Effect of Operational Changes in Reducing Fish Impingement at a Power Plant in Ohio, USA

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Abstract: Both intake volumetric flow and through-screen velocity (the velocity of water as it passes through the screen) are important variables affecting fish impingement at industrial water intake structures including those at power plants. However, there are limited data available on quantitative assessments of impingement following changes in power plant operation such as reduced volumetric flow and intake velocity. Impingement studies were conducted at Bay Shore Power Plant in 2005-2006 (baseline) and again in 2013-2014 following fish protection mitigation which included reduced intake volumetric flows (from $33.5 \text{ m}^3 \cdot \text{s}^{-1}$ to $9.1 \text{ m}^3 \cdot \text{s}^{-1}$), a reduced through-screen velocity (from approximately $79.2 \text{ cm} \cdot \text{s}^{-1}$ to $11.6 \text{ cm} \cdot \text{s}^{-1}$), modified traveling screens and installation of a fish-return system to gently and quickly remove any fish that were impinged back into the waterbody. A comparison of baseline and post-mitigation results suggested that with this mitigation in place, impingement reductions can exceed 90% for robust dominant fish species in the area.

Key words: Impingement, fish protection, cooling water intake structure, flow and velocity reduction, mitigation.

1. Introduction

Withdrawals of water for electricity generation at power plants can result in the impingement of aquatic organisms on intake exclusion screens. Some factors important in determining fish impingement rates include: configuration (surface or submerged) or location of intake (e.g., river, lake, reservoir, or ocean); intake water velocities; environmental conditions such as light level, and the level of recruitment of impinged fish [1]. Recruitment is defined as the number of fish surviving to enter a fishery (e.g., commercial and recreational) or to a given life stage (e.g., maturity) and thus a high recruitment level of a commonly impinged fish would mean a higher overall impingement rate. Another factor that plays a role in fish impingement rate is the intake volumetric flow rate of water intakes. However, the relationship between volumetric flow rate of water intakes and fish

impingement is quite variable, and a dose-response relationship is not consistent among power plants located on different water bodies in the USA [2]. Nevertheless, there may be regional exceptions. For example, for power plants on the Great Lakes, Kelso and Milburn [3] reported a direct relationship between the number of organisms impinged, plant size, and water usage.

Numerous fish protection technologies are available to reduce impingement and can be grouped into five basic categories depending on their mode of action [4]: (1) exclusion; (2) diversion (or passage); (3) behavioral; (4) collection/transfer; and (5) flow reduction or operational changes. Exclusion technologies physically exclude fish from entering the intake. Diversion technologies bypass fish from the intake flow and return them into the source waterbody. Behavioral devices use natural behavior patterns to attract or repel fish and target impingeable-sized organisms. Collection and transfer technologies handle fish during the transfer process and return them

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to the source waterbody (i.e., fish-return system) [4]. Flow reductions, although more of an operational change than actual technology, as implied, result in a reduction of flow to the intake to address impingement and entrainment. Furthermore, it is common for a mitigation technology to be used in combination with other technologies and this combination of technologies is termed an integrated system.

In 2012, the BSPP (Bay Shore Power Plant), situated on Maumee Bay, Ohio, USA, modified its existing integrated fish protection system to meet agency requirements for fish protection. These modifications included the installation of a fish-return system, installation of fish-friendly exclusion screens, and two operational changes—intake volumetric flow reduction and intake through-screen (the velocity of water as it passes through the intake exclusion screen) velocity reduction. The purpose of this evaluation was to determine whether, collectively, the reduced through-screen velocities and volumetric flow regime at BSPP, along with the installation of fish-friendly screens and a fish-return system, had been effective in reducing fish impingement mortality. Post-mitigation impingement sampling results from 2013-2014 were compared to baseline impingement sampling results in 2005-2006 (i.e., before the modified fish protection system was implemented). The fish-return system was also evaluated for residual fish impingement losses. Additionally, a DIDSON (Dual Frequency Identification Sonar, Sound Metrics, Bellevue, Washington) acoustic camera was used as a supportive technique to qualitatively assess fish behavior and movement in front of the intake screens.

2. Methodology

2.1 The Study Site

The BSPP is a coal-fired facility located on the southern shore of Maumee Bay, near the mouth of the Maumee River, at the western end of Lake Erie, near Oregon, Ohio. Cooling water is withdrawn from the Maumee River via an open intake channel and

discharged into Maumee Bay.

Prior to 2012, four units with a total capacity of 631 MW were in operation at BSPP and the intake volumetric flow rate was $33.5 \text{ m}^3\cdot\text{s}^{-1}$ or 764 MGD. Water entering the intake channel passed through trash racks (3 in spacing) and traveling screens (3/8 in mesh) with a through-screen velocity of $79.2 \text{ cm}\cdot\text{s}^{-1}$. Impinged fish were collected on the traveling screens, and emptied into a debris trough which was discharged into the discharge channel. No fish return system was present.

In 2012, a modified fish protection system was implemented with a reduced intake volumetric flow rate, a reduced intake through-screen velocity, and a reduced number of screens operating. In addition, a fish-return system was incorporated into the design. The components of the modified system included one operating unit (Unit 1—136 MW) with an intake volumetric flow of $9.1 \text{ m}^3\cdot\text{s}^{-1}$ (209 MGD), fish-friendly screens (six Atlas dual flow screens) with a through-screen velocity of $11.6 \text{ cm}\cdot\text{s}^{-1}$ and a gravity fed fish-return system to the intake channel. With these operational and technology changes in place, the intake volumetric flow was reduced to less than a third of the original intake volumetric flow, and the through-screen velocity was reduced to about 15% of the original through-screen velocity.

2.2 Impingement Sampling

Sampling was conducted at BSPP during a 12-month period from April 2013 to March 2014 to measure the quantities and species of fish impinged following post-mitigation involving mainly intake volumetric flow reduction to $9.1 \text{ m}^3\cdot\text{s}^{-1}$ (209 MGD) and through-screen velocity reduction to $11.6 \text{ cm}\cdot\text{s}^{-1}$. The sampling methodology used was similar to earlier impingement sampling in 2005-2006 but at a reduced level [5]. A total of 30 impingement sampling events were conducted with the frequency of sampling occurring weekly, biweekly, or monthly, depending on the month (Table 1). The frequency of sampling

was determined based on the analysis of previous impingement sampling results in 2005-2006. Thus, sampling occurred more frequently during periods when impingement was expected to be high and least frequently when impingement was expected to be low. Day time and night time sampling were carried out for each sampling event since light and visual cues can affect impingement [6]. Samples were also collected at sunrise and sunset to obtain a crepuscular measure. An in situ cage (1 cm or 3/8 in mesh) was set within the fish-return trough at the pumphouse to collect fish that were impinged upon and washed from the traveling screens typically over a 24-h period. For day sampling, samples were collected at 1, 2, 3 and 4 h after sunrise and for night sampling, samples were collected at sunset and 1, 2, 3 and 4 h after sunset. The duration of subsample was dependent upon the number of fish collected per unit time. For each sampling event, impinged fish were identified to the lowest practicable taxonomic level, sorted (by species), and enumerated. For each sampling event, the day, night, and crepuscular raw data collected were extrapolated to obtain a day time impingement estimate, night time impingement estimate, and crepuscular impingement estimate (e.g., 13.5 h for day time, 8.5 h for night time, and 2 h for crepuscular

time). These data were then summed to obtain the daily (i.e., 24-h) impingement estimate. The sampling data (i.e., counts of fish impinged by species and unit/screen on each sample date) were used to calculate impingement mortality.

With these data, estimates of the average daily impingement rate for a unit/screen at BSPP for each month and species was calculated as Eq. (1):

$$AIR_{ms} = \frac{\sum_{u=1}^4 \sum_{i=1}^{J_{mu}} (CT_{msiu} \times \frac{3}{P_{miu}})}{\sum_{u=1}^4 J_{mu}} \quad (1)$$

where, AIR_{ms} = adjusted daily mean impingement rate for species (s) at BSPP in month (m); CT_{msiu} = impingement count for species (s) at unit (u) on collection date (i) at BSPP in month (m); P_{miu} = number of pumps operating at unit (u) on collection date (i) at BSPP in month (m); J_{mu} = number of collection dates (i) at unit (u) in month (m).

Using these impingement rates, total impingement at BSPP for species (s) in month (m) was estimated as Eq. (2):

$$NI_{ms} = AIR_{ms} \times \sum_{u=1}^4 \sum_{d=1}^{N_{mu}} \left(\frac{P_{mdu}}{3} \right) \quad (2)$$

where, NI_{ms} = total impingement of species (s) at BSPP in month (m); P_{mdu} = total number of pumps operating at unit (u) at BSPP on day (d) of month (m); N_{mu} = number of days of operation at unit (u) at BSPP in month (m).

Table 1 Impingement sampling parameters and conditions at BSPP for the baseline program (2005-2006) and post-mitigation program (2013-2014). The 2013-2014 sampling program occurred following implementation of a modified fish diversion system which included intake volumetric flow and through-screen velocity reductions, fish-friendly screens, and a fish-return system.

Parameter/condition	2005-2006 (baseline)	2013-2014 (post-mitigation)
Intake volumetric flow ($\text{m}^3 \cdot \text{s}^{-1}$)	33.5	9.1
Velocity (through screen)	79.2 $\text{cm} \cdot \text{s}^{-1}$ (2.6 $\text{ft} \cdot \text{s}^{-1}$)	11.6 $\text{cm} \cdot \text{s}^{-1}$ (0.38 $\text{ft} \cdot \text{s}^{-1}$)
Sampling window	May 2005-April 2006, May 2006, October-December 2006	April 2013-March 2014
Frequency	(1) Twice weekly (May-November 2005, mid-March, April, May, November 2006) (2) Weekly (December 2005-mid-March 2006, October 2006, December 2006)	(1) Weekly (March, June, July, October-December) (2) Biweekly (May) (3) Monthly (January, February, April, August, September)
Total No. of events	104	30
Time of day	Day and night	Day and night
Sample duration	Variable—dependent on number of fish collected per unit time	Variable—dependent on number of fish collected per unit time

Annual estimates were determined by summing the monthly estimates.

The extrapolated 2013-2014 impingement results were compared to baseline results from 2005-2006 (i.e., before intake volumetric flows and through-screen velocities were reduced to current levels) (Table 1). Sampling in 2005-2006 was more intensive than in 2013-2014 with 4 months of additional data collected (May 2005-April 2006, and May, October, November, and December 2006). Sampling in 2005-2006 occurred either weekly or twice weekly depending on the month and key impingement periods. A total of 104 samples (85 samples plus 19 samples from the additional 4 months) were collected in 2005-2006. Samples were collected in bins placed at the traveling screen wash. A fish-return system had yet to be installed in 2005-2006. The identification, sorting, enumeration, and extrapolation of fish impingement data collected in 2005-2006 were carried out in the same manner as in 2013-2014. However, for the 4 months that were sampled twice in 2005-2006 (i.e., May, October, November and December), the 2 monthly estimates for each respective month (e.g., May 2005 and May 2006) were averaged to obtain one value so that data could be represented annually (as opposed to over a 16-month period).

Monthly and annual fish impingement percent reductions from baseline 2005-2006 sampling to 2013-2014 post-mitigation sampling were calculated as Eq. (3):

$$\% \text{ reduction} = 100 - (a/b \times 100) \quad (3)$$

where, a is the number of fish impinged monthly or annually in 2013-2014, and b is the number of fish impinged monthly or annually in 2005-2006.

A separate analysis of Gizzard Shad (*Dorosoma cepedianum*) impingement during the winter months (October to December) for 2013-2014 and 2005-2006 was also completed since Gizzard Shad in northern areas (e.g., Great Lakes region) are susceptible to massive winter die-offs [7]. For both sampling

programs, Gizzard Shad during the months of October to December were excluded from the impingement totals and the monthly and annual fish impingement percent reductions were re-calculated.

In 2013-2014, impingement survival studies were undertaken to assess immediate and latent mortality (24-48 h) of impinged fish. Collections occurred on a monthly basis with the exception of January 2014 and February 2014 where frozen conditions prevented sampling. The survival studies were conducted independently of the impingement study since fish collected for the impingement study were handled extensively. Control samples were collected using nets in front of the screenhouse to assess the condition of fish prior to entering the trash racks. All live fish collected were immediately placed into holding tanks and their condition was assessed immediately ($t = 0$), and at 24 h and 48 h. Similarly, juvenile and adult fish were collected from the fish-return system and assessed immediately and at 24 h and 48 h to provide an assessment of the combined mortality associated with the traveling screen and fish-return system. The key species considered in the survival assessment were Emerald Shiner (*Notropis atherinoides*), Freshwater Drum (*Aplodinotus grunniens*), and Gizzard Shad. The survival studies were conducted in a similar manner to survival studies conducted during the baseline study in 2005-2006 [8]. However, in 2005-2006, fish were collected at the traveling screen wash since the fish-return system was not yet installed.

2.3 Fish Movement and Behavior

The DIDSON unit was deployed on three dates in 2013 (May 22, June 24, and June 25) to collect “real-time” data on the responses of fish movement in the vicinity of the intake bar racks. The DIDSON was installed in a fixed location approximately 10-20 cm in front of the bar racks perpendicular to intake flow (Fig. 1). A frame rate of 6 per second was used during the deployment. The unit was deployed towards the

Fig. 1 Setup of DIDSON acoustic camera in front of bar racks.

northeast end of the intake on the upstream side of the bar racks in the middle of the water column. Qualitative observations were made to determine whether there were resident fish in the intake and whether fish were passing through the bar racks or avoiding them.

3. Results and Discussion

3.1 Impingement Sampling

An annual total of 6.5 million fish were estimated impinged in 2013-2014 during post-mitigation sampling (Table 2). The five dominant species accounting for approximately 100% of the fish impinged were: Gizzard Shad (88%), Emerald Shiner (6%), White Perch (*Morone americana*) (4%), Freshwater Drum (1%), and Bluegill (*Lepomis macrochirus*) (1%). Thirty other species were impinged comprising less than 1% of the total impinged.

Baseline impingement sampling results in 2005-2006

indicated that the annual impingement was 46 million fish (Table 2) with the following five species accounting for approximately 98% of the fish impinged: Emerald Shiner (52%), Gizzard Shad (31%), White Perch (10%), White Bass (*Morone chrysops*) (4%), and Spottail Shiner (*Notropis hudsonius*) (1%). Over 50 species comprised the remaining 2% impinged.

A comparison of fish impinged during the baseline sampling program and post-mitigation sampling program revealed that the three dominant species, comprising more than 93% of the total impinged for both programs, were Emerald Shiner, Gizzard Shad, and White Perch (Fig. 2). However, the composition of these three fish species differed in both sampling programs. In 2005-2006, Emerald Shiner comprised approximately half of the species impinged followed by Gizzard Shad, which comprised approximately one-third of the fish impinged, and White Perch

Table 2 Numbers of fish impinged at the Bay Shore Power Plant monthly and annually for 2005-2006 (baseline) and 2013-2014 (post-mitigation) and the percent impingement reduction of post-mitigation after implementation of the modified fish protection system.

Month	No. impinged (2005-2006)	No. impinged (2013-2014)	Reduction (%)
April	4,116,642	71,969	98.3
May	775,474	31,572	95.9
June	1,175,648	31,049	97.4
July	3,653,593	15,267	99.6
August	1,100,434	7,903	99.3
September	1,108,736	120,526	89.1
October	7,830,777	640,813	91.8
November	6,034,029	1,883,778	68.8
December	7,464,166	3,242,465	56.6
January	3,151,175	421,433	86.6
February	1,935,340	2,007	99.9
March	7,683,582	72,705	99.1
Total	46,029,596	6,541,487	85.8

Fig. 2 Percent composition of fish impinged at Bay Shore Power Plant during the baseline sampling year (2005-2006) and post-mitigation sampling year (2013-2014); mitigation included installation of a modified fish diversion system and reductions in intake volumetric flows and through-screen velocities.

comprised one-tenth of the fish impinged. In 2013-2014, the fish composition comprised almost entirely of Gizzard Shad (88%), with Emerald Shiner and White Perch together comprising one-tenth of the total impinged.

A comparison of the monthly and annual impingement estimates from the baseline (2005-2006) and post-mitigation (2013-2014) studies indicated that with the exception of 2 months (November and December) where percent impingement reduction was

68.8% and 56.6%, respectively, monthly impingement reduction at BSPP was > 85% with the annual reduction being 85.8% (Table 2). An estimate of reduction of Gizzard Shad alone between the 2005-2006 and 2013-2014 impingement results was approximately 60%, compared to a reduction of approximately 95% for White Perch, and a 98% reduction for Emerald Shiner.

In both the 2005-2006 baseline impingement study and 2013-2014 post-mitigation study, there was a substantial increase in Gizzard Shad impingement in the winter months (October to December) totaling more than 10 million and 5 million fish, respectively (Table 3). Large numbers of dead or dying Gizzard Shad were also observed in the intake channel. When Gizzard Shad mortality during the October to December period was excluded from data analysis, the baseline 2005-2006 annual impingement total

decreased from 46 million to 36 million and 2013-2014 post-mitigation annual total decreased from 6.5 million to 1.2 million (Table 4). The percent reduction comparing baseline and post-mitigation conditions also improved in these 3 months making the modified fish protection system no less than 86% effective on a monthly basis and increasing the annual efficiency to 96.6% compared to 85.8% (Table 2) when Gizzard Shad winter mortality was included in the analysis.

Impingement survival results for 2013-2014 for live fish collected suggested 100% immediate survival of all species and variable latent survival for species following passage through the fish-return system. For Emerald Shiner, 48-h survival of fish collected in the fish trough was good (range 73%-80%) in cooler months (e.g., April and November) but poor (range 0%-46%) in warmer months, including in the control

Table 3 Numbers of Gizzard Shad impinged at Bay Shore Power Plant from October to December for study years 2005-2006 and 2013-2014.

Month	No. impinged (2005-2006)	No. impinged (2013-2014)
October	5,555,938	555,494
November	841,846	1,782,191
December	3,687,490	2,974,018
Total	10,085,274	5,311,703

Table 4 Numbers of fish impinged at the Bay Shore Power Plant monthly and annually for 2005-2006 (baseline) and 2013-2014 (post-mitigation) excluding natural winter mortality of Gizzard Shad during the months October through December. The percent reduction represents the reduction of fish impinged post-mitigation after the modified fish protection system was implemented.

Month	No. impinged (2005-2006)	No. impinged (2013-2014)	Reduction (%)
April	4,116,642	71,969	98.3
May	775,474	31,572	95.9
June	1,175,648	31,049	97.4
July	3,653,593	15,267	99.6
August	1,100,434	7,903	99.3
September	1,108,736	120,526	89.1
October	2,274,839	85,319	96.2
November	5,192,183	101,587	98.0
December	3,776,676	268,447	92.9
January	3,151,175	421,433	86.6
February	1,935,340	2,007	99.9
March	7,683,582	72,705	99.1
Total	35,944,322	1,229,784	96.6

samples. A similar trend was seen for Freshwater Drum. For Gizzard Shad, 48-h survival of those collected in the fish troughs was poor (range 0%-31%), including for the months of October to December where natural winter mortality was expected. The survival results for 2005-2006 indicated overall poor latent survival after 48 h (range 3%-37%) including for Emerald Shiner in cooler months (e.g., February and November).

The impingement results at BSPP suggest that with the reduced intake volumetric flow and through-screen velocity, there is a significant reduction in impingement exceeding 95% for all species with the exception of Gizzard Shad. The swimming speeds of seven dominant species impinged at BSPP (Emerald Shiner, Gizzard Shad, White Perch, White Bass, Freshwater Drum, Yellow Perch (*Perca flavescens*) and Walleye (*Sander vitreus*)) which comprised 98.3% of total impinged in 2005-2006 were investigated and compared to the through-screen velocity at BSPP. The critical speeds based on measured sizes were first examined. Critical swimming speed is defined as the speed that can be maintained for a given period of time before fatiguing; and it is an accurate reflection of fish swimming performance in reference to velocity changes and to other abrupt changes in the environment. White Perch (< 150 mm) and Emerald Shiner (65 mm) have average critical velocities exceeding 30 cm·s⁻¹ at temperatures below 15 °C (spring temperatures) [2]. Other species such as Walleye, Yellow Perch, White Bass, and Spottail Shiner also have critical swimming speeds above 20 cm·s⁻¹. All of these species are expected to be capable of avoiding the intake bar racks, and displaying avoidance behavior to the 11.6 cm·s⁻¹ through-screen velocities at BSPP based on their swimming performance. Critical swimming speeds are generally difficult to measure, hence, the literature is not comprehensive. Thus, data were not available for either Freshwater Drum or Gizzard Shad. Therefore, the sustained swimming speeds (i.e., the

swim speed that can be maintained indefinitely) for all dominant fish species were examined under the assumption that fish with sustained swimming speeds exceeding the through-screen velocity of 11.6 cm·s⁻¹ would be capable of moving away from the screens and avoid impingement as their critical and burst swim speeds are expected to be higher than their sustained speeds [9]. All of the dominant fish species, including Freshwater Drum and Gizzard Shad, have both sustained and burst swimming speeds exceeding the through-screen velocity at BSPP suggesting that all species would be able to avoid screens and become impinged (Table 5).

Gizzard Shad impingement with mitigation in place still totaled 5,311,703 individuals and accounted for approximately 88% of the total fish impinged in 2013-2014 at BSPP. These fish were primarily juvenile and were typically less than 150 mm in total length. The predicted sustained swimming speed of 100-110 mm Gizzard Shad was estimated at 21 cm·s⁻¹ which far exceeded the estimated through-flow screen velocity (11.6 cm·s⁻¹). However, swim speed performance can be significantly influenced by temperature including cold shock [10]. Cold-shock stress occurs when fish are acclimated to a specific range(s) of temperature(s) and are subsequently exposed to a rapid decrease in temperature resulting in major physiological and behavioral changes, and even death [11]. Gizzard Shad are a southern species whose northern range extends into the Great Lakes. Massive winter die-offs of Gizzard Shad are a relatively common occurrence in the Great Lakes and other waterbodies in the same geographic extent (e.g., Oneida Lake, NY) [7, 12-14]. Fetzer et al. [14] examined Gizzard Shad mortality under natural field conditions in Oneida Lake, NY, and at experimental temperatures of 1, 2 and 4 °C. The field tests indicated low mortality until temperatures dropped below 8 °C, where high mortality (> 75%) of Gizzard Shad occurred. For the experimental treatments, little mortality occurred with a temperature decrease from

Table 5 Estimated sustained swimming speeds for dominant species impinged at Bay Shore Power Plant based on 2005-2006 sampling results found in Ref. [8]. The calculations are based on average size of the fish species impinged. The sustained swimming speeds for all species exceed the through-screen velocity of $11.6 \text{ cm}\cdot\text{s}^{-1}$ at Bay Shore Power Plant suggesting that these species should be able to avoid impingement.

Species	No. impinged (annual) (2005-2006)	Fish length (mm)	Sustained swimming speed ($\text{cm}\cdot\text{s}^{-1}$)
Emerald Shiner	24,050,877	66	13
Gizzard Shad	14,313,113	106	21
White Perch	4,769,163	100	20
White Bass	1,593,199	149	30
Freshwater Drum	225,706	158	32
Yellow Perch	159,379	159	32
Walleye	77,469	333	67

8°C to 4°C but higher mortality occurred at 4°C and the highest mortality occurred at 1°C and 2°C . Fetzer et al.'s [14] results suggested that Gizzard Shad mortality at low temperatures was caused by cold stress and the inability to acclimate. Similarly, at BSPP, field observations of moribund shad in the intake forebay and impingement results suggest that Gizzard Shad were experiencing cold shock stress. Thus, with cold shock, Gizzard Shad would not be able to swim away from the BSPP intake even though their sustained swimming speeds exceed the through-screen velocity.

In this analysis, it was assumed that populations of key species such as Emerald Shiner, White Perch and Gizzard Shad have not changed appreciably between the years when comparisons were made. The comparison of results between 2005-2006 and 2013-2014 did not take into account annual variations in fish species assemblages and abundance estimates. Based on data from the Great Lakes Fishery Commission's Lake Erie Committee Forage Task Group, the overall abundance of forage fish including Gizzard Shad, White Perch and Emerald Shiner was higher in 2013 (approximately $7,000 \text{ fish}\cdot\text{ha}^{-1}$) than in 2005-2006 (approximately $4,000\text{-}5,000 \text{ fish}\cdot\text{ha}^{-1}$) for the western basin of Lake Erie which includes Maumee Bay [15]. Gizzard Shad abundance in 2005-2006 was at a maximum of $550 \text{ fish}\cdot\text{ha}^{-1}$ while the 2013 abundance was $> 3,500 \text{ fish}\cdot\text{ha}^{-1}$ [15-17].

Although there was a higher abundance of forage fish in 2013-2014, there was still a reduction in impingement of these species.

Although immediate survival was high for all species in 2013-2014, an assessment of latent survival following transport in the fish trough suggested variable monthly survival of fish (e.g., Emerald Shiner and Freshwater Drum) ranging from 0% to 100% with variability attributed to water temperature. Earlier studies have shown that survival of captive fish is reduced in the summer months when intake temperature is elevated [5]. In the case of Gizzard Shad, which are likely weak or moribund due to cold shock in winter months, survival following transport through the fish trough was low, ranging from 0% to 31%. These survival results suggested that some fish are able to survive impingement at BSPP and be returned back into the waterbody.

There are several examples of technological improvements at power plants to reduce fish impingement in peer reviewed literature while more examples are available in grey literature. For example, Patrick et al. [18] reported that a barrier net acting as an exclusion and behavioral technology significantly reduced fish impingement at the Pickering Nuclear Generating Station on Lake Ontario. Similarly, the Ludington Pumped Storage Hydroelectric Plant on Lake Michigan and other power plants such as Bowline Point Station on the Hudson River and Chalk

Point Station on the Patuxent River have reported impingement reductions following barrier net deployment [19, 20]. An acoustic fish deterrent system was installed at the Doel Power Plant in Belgium to prevent fish from entering the cooling water intake with results suggesting that some fish species, especially those with accessory structures (e.g., swimbladder) that increase hearing abilities had impingement levels that were significantly reduced [21, 22]. However, information on operational changes such as intake volumetric flow reductions and through-screen velocity reductions on fish protection are not readily available.

3.2 Fish Movement and Behavior

The DIDSON results indicated the presence of numerous fish in the vicinity of the intake (Fig. 3). Individual and schooling fish approaching the bar racks exhibited avoidance responses. For example, when traveling perpendicular to the bar racks, fish encountering the bar racks exhibited a V-shaped response away from the bar racks. Fish were also

observed swimming parallel with the bar racks. However, limited passage of fish occurred from in front and behind the bar racks.

The results of DIDSON analysis also support the notion of dominant fish species near BSPP having swimming speeds exceeding the through-screen velocity of $11.6 \text{ cm}\cdot\text{s}^{-1}$ as there was no evidence of fish impinging against the bar racks. Fish were seen either swimming parallel with the bar racks or exhibiting avoidance responses when approaching the bar racks. Thus, the reduced intake through-screen velocity of $11.6 \text{ cm}\cdot\text{s}^{-1}$ at BSPP is generally protective of fish and also meets several requirements or recommendations for fish protection. For example, the United States Environmental Protection Agency, under §316b of the Clean Water Act, has finalized as one of its compliance alternatives for once through cooling facilities that an intake through-screen velocity of $15 \text{ cm}\cdot\text{s}^{-1}$ or less is considered “Best Technology Available” and may make a facility compliant with impingement reduction requirements [23]. Other researchers have also concluded that a

Fig. 3 DIDSON image of typical fish behavior in front of the bar racks.

screening criterion of $15 \text{ cm}\cdot\text{s}^{-1}$ in front of the intake is important in reducing fish impingement at once through cooling facilities [9, 24]. In England and Wales, a design fish-escape velocity of $30 \text{ cm}\cdot\text{s}^{-1}$ is able to meet best practice requirements, as outlined in the best practice guide for intake and outfall screening [25].

4. Conclusions

Overall, the integrated fish protection system consisting of reduced intake volumetric flows, reduced through-screen velocities, fish friendly screens and a fish return system has been effective in reducing fish impingement mortality at the Bay Shore Power Plant. The results suggested that with this mitigation in place, impingement reductions can exceed 90% for robust dominant fish species in the area.

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