LABORATORY EVALUATION OF FILTREX FILTER SYSTEM FOR PROTECTING ICHTHYOPLANKTON AT A DESALINATION FACILITY INTAKE

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INTRODUCTION

Inima/Aquaria is constructing a desalination plant on the Taunton River in Dighton, Massachusetts. To protect aquatic resources, they are proposing to install a Filtrex Filtration System comprising racks of candles through which water from the river will be withdrawn. The pore size (40 μ) of the Filtrex candles is sufficiently small to prevent entrainment of all ichthyoplankton and other small organisms. The low through-pore velocity (0.2 ft/s) will prevent impingement of juvenile fish and should minimize impingement of fish eggs and larvae. However, until now, there were no data available to assess the actual risk of impingement for ichthyoplankton that may encounter the intake filter system at the Taunton River Desalination Plant (TRDP). Consequently, Alden was contracted to conduct a controlled laboratory study examining impingement rates and survival of impinged organisms exposed to a sub-set of Filtrex candles operated as they would be in the field (i.e., same operational cycle and withdrawal flow rate).

Study Objectives

The primary objectives of the laboratory evaluation of the Filtrex candles were to estimate impingement and survival rates of eggs and larvae released upstream of the candles at a channel velocity that was representative of the intake location on the Taunton River. White perch and river herring (blueback herring and alewife) were initially selected for testing based on concerns expressed by the resource agencies for these species at the site of the intake. However, only river herring (blueback herring eggs and larvae and alewife larvae) could be obtained for testing. American shad were also evaluated as an alternative species prior to the acquisition of river herring.

METHODS

Test Facility Design and Operation

Tests with the Filtrex candles were conducted in a Plexiglas flume (Figure 1). The inside dimensions of the test flume were 8 inches wide and 16 inches deep. The total length of the flume was 18 ft. Flow through the flume channel was generated with a 15-hp pump. Channel flow rate and velocity were controlled with a wheel valve on the pump discharge. Set points for target channel velocities were established using a Swoffer propeller velocity meter and a differential pressure cell interfaced with a computer. Prior to each test, the channel velocity was set using the wheel valve and then confirmed with both the differential pressure readings (inches of water and voltage) and with the Swoffer velocity meter readings.

An array of 6 Filtrex candles (two rows of three) was installed towards the downstream end of the flume (Figure 1). A separate pump was used to withdraw flow through the candles at a rate of about 9.25 gpm, resulting in a total filter withdrawal rate of 55.50 gpm. The filter flow rate was controlled with a ball valve on the filter pump discharge. Similar to the channel flow, the total filter flow rate was set using a differential pressure cell.

A fine-mesh containment screen was located at the upstream end of the channel to provide a relatively uniform flow distribution in the flume upstream of the candles and to prevent larvae from exiting the test enclosure in the upstream direction. A plankton net with 200 micron mesh was located at the downstream end of the test flume to collect eggs and larvae that passed by the candle array during each trial (Figure 1). A collection screen, also with 200 micron mesh, was inserted immediately downstream of the candles to collect impinged organisms after the filter withdrawal flow was turned off and when the candles were back flushed.

Test Fish Acquisition and Holding

The species selected for the evaluation of the Filtrex candles initially were white perch (*Morone americana*) and river herring (blueback herring *Alosa aestivalis* and alewife *Alosa pseudoharengus*). However, white perch, which are not a cultured species, could not be obtained by sources in Delaware, Maine, and Massachusetts, all of who attempted to capture spawning or gravid adults from which eggs and milt could be stripped. We attempted to obtain white bass (*Morone chrysops*) eggs as a surrogate for white perch from a source in Missouri, but they were also unsuccessful in their attempts to collect viable eggs from spawning adults.

Aquatic Resources Development (ARD) of Waldoboro, Maine, was successful in stripping and fertilizing eggs from alewife trapped in a small river and were also able to collect fertilized eggs from blueback herring that were also trapped, but held in tanks until they were ready to spawn. Fertilized American shad (*Alosa sapidissima*) eggs collected in a similar manner as the blueback herring eggs were also obtained from ARD. Larvae of all three species used in testing were hatched from all or a portion of the eggs received from ARD.

Eggs and larvae were held in a re-circulating holding facility specifically designed for ichthyoplankton and that was connected to the test facility (i.e., the same water was re-circulated through both facilities). Water quality (pH, salinity, dissolved oxygen, temperature, hardness, alkalinity, and ammonia) were monitored daily. Water temperature was maintained between about 16.6 and 17.8 ^{o}C, dissolved oxygen between 6 and 8 ppm, pH between 7 and 8, and salinity was about 1.4 ppt. Eggs were held in McDonald hatching jars and, after hatching, larvae were placed in rectangular aquariums. Post yolk-sac larvae were fed live rotifers.

Test Conditions and Procedures

The evaluation of the Filtrex candles consisted of releasing eggs or larvae upstream of the candles and collecting impinged and bypassed organisms after a 14-minute filter withdrawal period, a 2-minute filter-off period, and a 2-minute filter back-flushing period. The 14-minute filter withdrawal and 2-minute off period is the expected operational cycle of the TRDP intake. Back flushing of the intake system will occur during the brine release cycle. With the exception of American shad egg trials, all tests were conducted with a channel velocity of about 1.1 ft/s, which was established as the minimum velocity of river flow passing the TRDP intake during operation. Tests with American shad eggs were conducted at a velocity of 1.5 ft/s, after which it was decided to test with the lower velocity (1.1 ft/s) to represent maximum exposure time of ichthyoplankton passing the candles. All trials were conducted with a filter withdrawal flow rate of approximately 9.25 gpm per candle, resulting in a total intake flow of 55.50 gpm and a through-slot velocity of about 0.20 ft/s. The withdrawal rate of 9.25 gpm per candle is the maximum rate proposed by Inima/Aquaria for the operation of the TRDP intake. The maximum back flushing flow rate that was attainable with the laboratory test facility was about 6 gpm per candle (36 gpm total).

Each species and life stage was evaluated under clear water conditions (i.e., no debris or turbidity). Testing with turbid water was also conducted with blueback herring eggs and larvae to determine whether suspended solids and debris present at the actual intake might affect impingement rates or survival of impinged ichthyoplankton. For these tests, sediment and small debris from a local pond was introduced into the test system to achieve turbidity levels between about 10 and 15 NTU. This turbidity level range was selected based on a sample taken in the Taunton River in the vicinity of the TRDP intake.

Each trial was initiated by introducing 100 eggs or larvae about 40 inches upstream of the candle array after the channel velocity and withdrawal flow rate were set to the specified conditions and the downstream net was positioned to collect bypassed ichthyoplankton (Figure 1). When the 14-minute filter withdrawal period ended, the test channel velocity was reduced to about 0.25 ft/s and the impingement collection screen was inserted immediately downstream of the candles (Figure 1). Although a channel velocity of 1.1 ft/s may have resulted in more impingements releasing from the candles during the periods without withdrawal flow and with back flushing, the lower velocity (0.25 ft/s) was required to prevent overtopping of the impingement collection screen. The downstream net was removed and rinsed to collect ichthyoplankton that passed downstream of the candles. Following the collection of bypassed organisms, the downstream net was returned to the fishing position and the impingement collection screen was removed and rinsed to collect any organisms that floated free from the candles during the 2-minute period with no filter flow. The impingement collection screen was repositioned and the candles were then back flushed. After 2 minutes of back flushing, both the impingement collection screen and the downstream net were removed and rinsed. Any ichthyoplankton collected in the downstream net after this second sample were assumed to have passed downstream while the impingement collection screen was removed and rinsed after the 2-minute filter-off period. Using these test procedures, three replicate trials were conducted for each combination of test conditions (i.e., species, life stage, and turbidity).

Bypassed and impinged ichthyoplankton recovered from each location (i.e., bypassed eggs and larvae, released impingements with no flow, and released impingements with back flushing) were enumerated and identified as live or dead. Live organisms from each sample (i.e., the two downstream net samples, the filter-off sample, and the filter back-flush sample) were placed in 1-liter beakers with air stones and held for 48 hours to assess latent mortality. The beakers were placed in a table bath with water circulated from the test facility pool to ensure that the post-test holding water temperature was the same as that during testing. For egg trials, hatched larvae and dead eggs were counted and removed after 24-hours and all hatched larvae and live and dead eggs were counted at the end of the 48-hour post-test holding period. For tests with larvae, mortalities were counted and removed after 24-hours and live and dead larvae were counted after

48 hours. An entrainment collection net (335 micron) was used to sample the candle withdrawal flow during tests with blueback herring larvae, but not with any of the other species or life stages. Entrainment sampling was added to the test program after trials with American shad eggs and larvae, alewife larvae, and blueback herring eggs were completed to confirm the pore size of the candles (40 μ) was sufficiently small to prevent the entrainment of ichthyoplankton.
In addition to the impingement tests, control trials were conducted to assess handling-related mortality and collection efficiency of the downstream net and impingement collection screen. For most of the test conditions evaluated we conducted the following control/collection efficiency tests:

- **Handling control:** 100 eggs/larvae were placed directly into a beaker with an air stone and held for 48 hours in the water bath.

- **Downstream net control and collection efficiency:** 100 eggs/larvae were released downstream of the candles with a flow of 1.1 ft/s (Figure 1) to determine collection-related mortality and collection efficiency of the downstream net. Eggs/larvae were collected 14 minutes after release (i.e., same duration as impingement trials).

- **Impingement collection screen control and collection efficiency:** 100 eggs/larvae were released between the candles and the impingement collection screen to determine collection-related mortality and collection efficiency of this screen. Similar to the collection of impinged eggs/larvae released from the candles during filter-off and back-flushing periods, control groups were released with a channel velocity of 0.25 ft/s and removed from the impingement collection screen two minutes after release.

Control groups were subjected to identical handling procedures as the impingement trial groups (i.e., rearing, counting methods, collection, and latent mortality holding). Thus, the only major difference between control and treatment groups was exposure to the Filtrex candles. Live eggs/larvae recovered during control trials were also held for 48 hours to assess latent mortality.

Additional collection efficiency trials were conducted with alewife larvae because a relatively large number of released fish were unaccounted for during impingement trials, and collection efficiencies of the downstream net and the impingement collection screen were near or at 100%. The additional collection efficiency trials were designed to determine if unrecovered larvae were impingements that did not release from the candles after the intake flow was turned off or during the back-flushing period. All the additional trials involved releasing larvae upstream of the filter array and collecting them in the downstream net with the following filter operating conditions: (1) filter intake flow off for 14 minutes; (2) filter back flushing for 14 minutes; (3) filter flow off for 14 minutes followed by back flushing for 2 minutes.

We initially planned to videotape all egg and larvae impingement trials to observe the interaction of ichthyoplankton with the Filtrex candles and the release of impinged organisms after the filter flow was turned off and when back flushing occurred. Also, we had planned to dye all eggs with methylene blue stain to improve their visibility. However, due to their small size (about 1 mm) and fragility, it was decided not to dye alewife eggs. The larger and more durable American shad eggs were successfully dyed and videos of tests with this species and life stage were obtained using a digital Sony hand-held video camera. Larvae were not dyed due to the potential for high mortality from the staining process, therefore it was impractical to videotape trials with this nearly-transparent life stage.

Data Analysis

Impingement rates were calculated for each set of conditions evaluated (i.e., combination of species, life stage, and turbidity) using the following equation:

$I = (n + b + d + a) / R$

Where:

I = estimated impingement rate;

n = number of impinged organisms collected after 2-minute filter-off period and adjusted for the collection efficiency of the impingement collection screen;

b = number of impinged organisms collected after 2-minute back-flushing period and adjusted for the collection efficiency of the impingement collection screen;

d = number impinged organisms collected in the downstream net when the impingement collection screen was removed between the filter-off and back-flush periods;

a = released organisms not accounted for after adjusting the bypassed and impingement numbers for collection efficiency; and

R = the number of organisms released

If collection efficiency of the downstream net was less than the actual number of fish recovered during an impingement trial, then the number of fish collected from this location was capped so that the total number of fish collected from all locations combined did not exceed the number released. For example, if 85 of 100 larvae were collected in the downstream net and the collection efficiency for this location was 80%, then the adjusted number collected would be 106. After adding the number impinged, the adjusted total recovered would be well over the number released (100). This approach, combined with assigning eggs/larvae that were not accounted for as impingements, provides for a conservative impingement rate estimate (i.e., actual rates for each set of test conditions may be lower). An arcsine transformation was used to better approximate a normal distribution for the proportion impinged (Zar 1984), which was typically skewed towards zero. Means and confidence intervals were calculated with the transformed data, then back transformed to proportions.

Immediate, 48-hr, and total survival rates were calculated for bypassed and impinged ichthyoplankton and for all control trials. Immediate survival was calculated by dividing the number of eggs/larvae recovered live by the total number recovered (live + dead). Forty-eight hour survival rates were calculated by dividing the number live at the end of the delayed mortality holding period by the total held (for eggs, the total live included hatched larvae and live eggs). Total survival was calculated by multiplying the immediate survival rate by the 48-hour survival rate.

RESULTS

American Shad

American shad was the first species evaluated during the study. Although American shad are not a species of concern at the plant intake, they are closely related to alewife and blueback herring (i.e., same genus) and were available from a reliable source at a time when it was not certain if either of the river herring species could be acquired for testing. American shad eggs tested with the Filtrex candles were approximately 3.1 mm in diameter (Table 1). Shad larvae were hatched from eggs that were not used in testing. The post yolk-sac larvae that were tested averaged 10.2 mm in length and had a mean head capsule width of 1.0 mm (Table 1). Shad eggs were evaluated with a channel velocity of 1.5 ft/s and larvae with a velocity of 1.1 ft/s. The withdrawal flow through the candles was maintained at 9.25 gpm per candle (55.50 gpm total) for all tests. Detailed impingement data for each trial conducted with American shad eggs and larvae are provided in Appendix A. Detailed survival data for bypassed, impinged, and control fish are provided in Appendix B.

Collection efficiency of shad eggs in the downstream net and impingement collection screen was 99% for both locations (Table 2). After adjusting the number of fish bypassed and impinged for collection efficiency, a total of 7 eggs were unaccounted for and assigned as impingements. Using the adjusted numbers for each collection location, the mean impingement rate for American shad eggs released upstream of the candles was 7.4% (Table 3), indicating that approximately 92.6% of released eggs passed downstream without impinging. All impinged eggs were recovered during the two minute period with the filter flow off. No impingements were collected after back flushing the candles (Appendix A, Table A-1). All impinged eggs were recovered live.

The collection efficiency of shad larvae was also 99% at both collection locations (Table 2). After adjusting the number of fish bypassed and impinged for collection efficiency and assuming unaccounted for fish were impinged, the mean impingement rate of American shad post yolk-sac larvae was estimated to be 10.1% (Table 3), with 89.9% of released larvae passing downstream without impinging. Sixteen shad larvae were recovered after the filter flow was turned off and nine were recovered during the two-minute back-flushing period (Appendix A, Table A-1). All impinged larvae were recovered dead.

Immediate survival of American shad eggs collected in the downstream net was 99.2% (Table 4). Immediate survival of impinged eggs recovered from the impingement collection screen was 100% (Table 4). Immediate control survival rates for each recovery location were also high (97% for the downstream net and 100% in the impingement collection screen; Table 4). Survival during the 48-hour latent mortality period was 68.7% for bypassed eggs collected downstream and 90.9% for impinged eggs recovered in the impingement collection screen (Table 4). The 48-

hour survival rate of controls collected from the downstream net was 40.6%, whereas it was 99% for controls recovered from the impingement collection screen (Table 4). The control survival data indicate that mortality of eggs recovered downstream was most likely caused by injuries suffered in the downstream net. The high survival rate of controls recovered from the impingement collection screen suggests that, even though low, the mortality of impinged eggs likely was due to impingement-related injuries. However, handling control survival was 95% (Table 4), which demonstrates that the process of counting eggs into beakers and holding them for 48 hours likely caused some of the mortality observed for eggs recovered from the downstream net and the impingement collection screen.

Immediate survival rates for American shad post yolk-sac larvae were low for bypassed (11.4%) and impinged fish (0%) recovered after the filter flow was turned off and during back flushing (Table 5). Immediate survival of controls collected from the downstream net was 0% (Table 5), indicating that all mortality of larvae that passed downstream of the candles was due to recovery in the net. Immediate survival of controls recovered from the impingement collection screen was 77.8%, but 48-hour survival was only 13%, resulting in a total survival rate of 10.1% (Table 5). This demonstrates that immediate mortality of recovered impingements was likely due to impingement-related injuries. The 48-hour survival rate of handling controls (73.0%) indicates that delayed mortality of control larvae collected in the impingement collection screen was mainly due to the recovery process, but as much as 27% likely resulted from counting larvae into a beaker and holding them for 48-hours.

River Herring (Alewife and Blueback Herring)

Alewife and blueback herring are collectively referred to as river herring and both are species of concern at the TRDP intake. Alewife eggs were obtained first, but hatched before they could be tested as eggs. Consequently, they were evaluated immediately after hatching (i.e., as yolk-sac larvae) at a mean length of 3.9 mm and head capsule width of 0.6 mm (Table 1). Alewife larvae were only tested with clear water. Blueback herring were tested as eggs and post yolk-sac larvae with clear and turbid water. The mean diameter of blueback eggs was 1.1 mm (Table 1). Blueback larvae averaged 5.6 and 6.7 mm in length for tests with clear water and 6.9 mm in length for tests with turbid water (Table 1). The mean head capsule width of blueback herring larvae was about 0.5 mm for the smaller fish and 0.7 mm for the larger ones (Table 1). All tests with alewife and blueback herring were conducted with a channel velocity of 1.1 ft/s and withdrawal flow through the candles was maintained at 9.25 gpm per candle (55.50 gpm total). Detailed impingement data for each trial conducted with these two species are provided in Appendix A. Detailed survival data for bypassed, impinged, and control fish are provided in Appendix B.

Blueback Herring Eggs

Collection efficiency rates for blueback herring eggs tested with clear water were 96% for the downstream net and 99% for the impingement collection screen (Table 6). Collection efficiency rates were lower for turbid water tests, 79% for the downstream net and 84% for the impingement collection screen (Table 6). The lower recovery rates for the turbid water control trials was mainly due to the increased difficulty in finding and sorting eggs amongst the introduced debris and sediment. Only three eggs were recovered dead from the impingement collection screen at the end of the 2-minute control period with clear water, and only one was recovered dead after the control period with turbid water (Table 6). Survival data for blueback herring eggs was inadvertently not recorded for control trials with the downstream net under either water clarity condition.

After adjusting the number of eggs bypassed and impinged for collection efficiency and assuming unaccounted for eggs were impinged, mean impingement rates of blueback herring eggs tested with clear and turbid water were 7.8% and 5.8%, respectively (Table 7). During the clear water trials, all impinged eggs recovered after the filter was turned off and after back flushing were recovered live. Two of the 11 recovered impingements were collected after the candle flow was turned off and the other nine were recovered during back flushing (Appendix A, Table A-2). During turbid water trials, 3 of 15 recovered impingements were collected dead. Six of the 15 impinged eggs were recovered during the filter-off period and nine during back flushing. The impingement data for blueback herring eggs demonstrates that accumulation of suspended sediments and small debris on the candles does not result in higher impingement rates for this species and life stage.

Immediate survival rates for blueback herring eggs tested with clear water were high for bypassed (95.1%) and impinged fish (100%) recovered after the filter flow was turned off and during back flushing (Table 8). The one impinged egg collected after the filter flow was shut off during the clear water trials died during the 48-hour post-test holding period. Only 2 of the 9 impingements collected after back flushing died during the same period. Immediate survival of blueback herring eggs collected in the downstream net during turbid water tests was also high (94.4%), but immediate survival of impinged eggs was lower than observed for clear water trials (Table 8). Immediate and delayed survival rates for control groups released directly into the impingement collection screen under both water clarity conditions ranged from 87.5 to 98.8%; total survival rates were 84.8% for clear water and 96.4% for turbid. Handling control survival after 48 hours was 87% for clear and turbid water tests (Table 8). Although high, the control survival rates indicate some of the mortality experienced by impinged fish was due to handling procedures. The small number of impingements collected during tests with the two water clarity conditions makes it difficult to fully assess impingement-related mortality and to make any definitive conclusions regarding survival of eggs released from the candles after the filter flow was turned off or following back flushing. However, as with impingement rates, the survival data indicate that turbidity and accumulation of fine debris on the candles does not appear to result in increased mortality of impinged eggs.

Alewife and Blueback Herring Larvae

Collection efficiencies for alewife yolk-sac larvae recovered in the downstream net and the impingement collection screen were 96 and 100%, respectively (Table 9). Mortality in the downstream net was 100%, whereas all control fish were recovered live from the impingement collection screen. Three additional controls were conducted with alewife larvae because a large number of fish were unaccounted for at the completion of impingement trials. The additional control trials were designed to determine if unrecovered fish were impinging on the candles and not dislodging during the 2-mintue filter-off and back-flushing periods. For all the additional trials, control fish were released upstream of the candles. The first release was conducted with the filter flow off for 14 minutes, the second with the filters back flushing for 14 minutes, and the third with the filters off for 14 minutes and back flushing for 2 minutes. Collection efficiencies were 66% for the trial with the filters off, 78% for the trial with the filters off followed by back flushing, and 92% with just back flushing (Table 9). These results demonstrate that yolk-sac larvae were impinging on the candles, even when they were not withdrawing flow, and that back flushing did not result in most larvae dislodging from the candles. Consequently, alewife larvae that were not recovered during impingement trials were likely impingements that remained on the candles after the filters were turned off and back flushed.

Blueback herring post yolk-sac larvae had high collection efficiencies (98% or greater) for the downstream net during trials with clear and turbid water (Table 10). Collection efficiencies of control groups released in front of the impingement collection screen were 84% for 5.7-mm fish, 97% for 6.7-mm fish, and 92% for 6.9-mm fish. No blueback herring larvae were recovered live from the downstream net during control trials and 36 or less were recovered live from the impingement collection screen (Table 10). Additional control trials with releases upstream of the candles were not required for blueback herring post yolk-sac larvae because the number of unrecovered fish was low for impingement trials with this species and life stage.

After adjusting the number of larvae bypassed and impinged for collection efficiency and assuming unaccounted for fish were impinged, the mean impingement rate of alewife yolk-sac larvae tested in clear water was 58.1% (Table 11). Mean impingement rates of the two size groups of blueback herring post yolk-sac larvae tested with clear were 15.3% for the smaller fish (5.6 mm) and 11.1% for the large fish (6.7 mm) (Table 11). The mean impingement rate for post yolk-sac larvae (6.9 mm) evaluated with turbid water was 13.1% (Table 11). These data demonstrate that significant reductions in impingement occur after larvae lose their yolk sac and reach lengths greater than 5 mm. The data also indicate that accumulation of suspended sediments and small debris on the candles does not result in higher impingement rates for these two species and life stages.

When all of the data from both species and all size groups are combined, about 39% of recovered impingements were collected after the two-minute period with no filter flow and 61% after back flushing. Immediate survival of alewife and blueback herring larvae recovered in the downstream net was 1.7% and 0.0%, respectively (Table 12). Immediate survival of control fish recovered from the downstream net was 0% for larvae of both species, indicating that mortality of larvae recovered after passing the filter candles was due to injury associated with the collection net. Immediate survival rates of control groups released in front of the impingement collection screen were 100% for alewife and 32 to 39% for blueback herring trials (Table 12). Based on the observed survival rates of blueback herring larvae evaluated with clear and turbid water (Table 12), there was no apparent effect of debris on the survival of impinged or bypassed fish. All but two river herring larvae impingements were recovered dead after the filters were turned off and following the back-flushing period (Appendix A, Table A-2). Given that immediate survival of control fish recovered from the impingement collection screen was 100% for alewife, it is likely that the high mortality rate of impinged yolk-sac larvae was due to impingement-related injuries. However, for blueback herring post yolk-sac larvae, control survival data indicated as much as two thirds of the immediate mortality suffered by impinged fish may have been due to the collection process and not impingement on the candles.

Entrainment sampling conducted during tests with blueback herring larvae demonstrated that no fish passed through the candles during filter withdrawal periods. The lack of entrainment of blueback herring larvae indicates that American shad eggs and larvae, alewife yolk-sac larvae, and blueback herring eggs also were not entrained based on their head capsule widths and egg diameters (Table 1).

CONCLUSIONS AND DISCUSSION

The laboratory evaluation of the Filtrex Filtration System was successful in collecting baseline impingement and survival data for three fish species and life stages. The test facility design and operating conditions were the same or similar to those expected for full-scale intake at the TRDP (i.e., candle spacing, filter withdrawal flow, channel velocity). Some tests were also conducted with introduced debris to mimic the potential effects of turbidity at the intake site on impingement rates and the survival of impinged organisms. The following are the primary conclusions drawn from the results of the laboratory study:

- Impingement rates of American shad eggs and blueback herring eggs were low (< 8%) and survival rates of impinged eggs were relatively high (typically greater than 75%, including 91% for American shad eggs)

- The impingement rate of alewife yolk-sac larvae with a mean length 4.7 mm was relatively high (58.1%)

- Impingement rates for blueback herring post-yolk sac larvae with mean lengths of 5.6 to 6.9 mm were low (about 15% or less). The mean impingement rate of American shad post yolk-sac larvae with a mean length of 10.2 mm was also low (10.1%). These data suggest that once larvae lose their yolk sacs and attain lengths greater than 5 mm, protection from impingement will be considerably higher than it is for yolk-sac larvae less than 5 mm.

- Survival of impinged American shad post yolk-sac larvae was 0%, whereas immediate control survival for fish collected from the impingement collection screen was 77%. These results indicate that most impingement mortality was likely due to impingement-related injuries.

- Survival of impinged alewife yolk-sac larvae was low (33% for impinged larvae collected after the candle flow was turned off and 0% after back flushing), whereas immediate survival of control fish collected from the impingement collection screen was 100%. Consequently, mortality of impinged alewife larvae can be attributed to impingement-related injuries.

- The survival rate of impinged blueback herring post yolk-sac larvae was 0%. Immediate survival of control fish was 32% for clear water trials and 36% for turbid water trials. These results indicate that about two thirds of the immediate mortality observed for impinged blueback herring larvae may have been due to collection and handling procedures.

- Although recovery rates of released eggs and larvae were generally high (about 90% or greater), some fish were unaccounted for after adjusting the data for the collection efficiency of each recovery location. Unaccounted for eggs and larvae were assumed to be impingements that did not release from the candles after the filter flow was turned off or following back flushing. Based on an additional set of collection efficiency trials, the number of alewife yolk-sac larvae that remained on the candles after turning the filter flow off and back flushing ranged from 29 to 53%. The percent of unaccounted for American shad eggs, blueback herring eggs, and post yolk-sac larvae that may have remained impinged after the completion of each trial was typically between 0 and 9%.

- Based on the result of turbid water tests with blueback herring eggs and post yolk-sac larvae, accumulation of suspended sediments and small debris on the candles did not appear to affect impingement rates or the survival of impinged organisms.

- Entrainment sampling of the filter withdrawal flow during blueback herring tests confirmed that ichthyoplankton of this length (about 5 to 7 mm) and width (0.5 to 0.7 mm) are too large to pass through the candle pores (40 μ). These data also suggest that river herring eggs (about 1 mm in diameter) and yolk-sac larvae (3.9 mm in length and 0.6 mm wide) are also too large to pass through the candle pores.

It's difficult to compare the results of the Filtrex laboratory evaluation with those of other intake screening technologies due to the unique design of the candles, including the small pore size (40 μ) and low through-slot velocity (0.2 ft/s). Cylindrical wedgewire screens usually have slot widths of 0.5 mm or greater and they typically have been evaluated with slot velocities of 0.5 ft/s or higher. Also, most screening studies have focused on entrainment rates and not survival of bypassed or impinged organisms. In one of the few studies that have evaluated survival, Alden (2004a) estimated survival rates to be greater than 93% for American shad eggs that passed over a wedgewire screen with a slot velocity of 0.25 ft/s and sweeping velocities of 0.5 and 1.0 ft/s, which is similar to what was observed with the Filtrex candles.

Impingement and entrainment rates typically have been low for wedgewire screens, particularly when sweeping velocities (i.e., ambient currents) are equal to or greater than the slot velocity (Alden 2004b). The sweeping (or channel) velocity in the Filtrex laboratory tests was about four times the through-slot velocity of the candles. This high ratio of sweeping velocity to slot velocity is likely the primary reason that impingement rates were low for all species and life stages evaluated, with the exception of the alewife yolk-sac larvae. The sweeping velocity used for the study (1.1 ft/s) was selected because it is the minimum ambient velocity that is expected to occur at the TRDP intake. Higher sweeping velocities will occur during certain portions of the tidal cycle and should result in even lower impingement rates. Although debris loading on fish screens and other types of intake technologies may affect impingement rates and survival of impinged organisms, the results of turbid water tests demonstrated that accumulation of suspended sediments and small debris on the candles did not result in higher impingement rates or increased impingement-related mortality.

In a laboratory evaluation with another screening technology, the Gunderboom filter barrier, it was demonstrated that impingement survival was relatively high (> 90%) for white sucker, common carp, and bluegill ichthyoplankton with flow only passing through the filter material (i.e., no sweeping or channel flow) (EPRI 2004). Impingement survival rates of rainbow smelt and striped bass larvae were considerably lower, but control survival for these species was also lower. Entrainment occurred for all of the species tested with the Gunderboom filter material, which was tested with perforations of 0.5, 1.0, and 1.5 mm inserted to increase the withdrawal flow rate. Entrainment was higher for the larger perforations. It is difficult to directly compare the results of these tests with those of the Filtrex candles because different species and flow conditions were evaluated. Also, impingement rates of ichthyoplankton have not been estimated for the Gunderboom system like they have for the Filtrex candles and cylindrical wedgewire screens (i.e. organisms released upstream with the ability to pass downstream after encountering the technology being evaluated). However, the overall effectiveness of the Gunderboom and Filtrex systems may be comparable under the conditions at the TRDP intake, particularly if the Gunderboom material is perforated (i.e., entrainment occurs) and/or impingement survival decreases in the presence of sweeping flows and/or debris.

The results of the laboratory study suggest that American shad and river herring eggs and post yolk-sac larvae could experience low impingement rates (15% or less) at a full-scale Filtrex Filtration System installed at the TRDP intake. However, impingement of alewife yolk-sac larvae was high (58%). When interpreting these results with respect to what will happen at the TRDP intake, it is important to consider what life stages are most likely to encounter the intake, what is the probability they will pass through the filter system based on the percent of river flow that is being withdrawn, and what is the expected distribution of fish throughout the river channel. Even with an impingement rate of 58%, only a small portion of the total number of yolk-sac larvae passing downstream in the river flow may become impinged if intake withdrawal rates are low (5% or less of total river discharge) and/or most larvae are mainly in the middle of the river or at a depth where they pass under or over the intake. Based on observations of American shad eggs released over a wedgewire screen with no channel flow and a slot velocity of 0.25 ft/s (Alden 2004a), the low through-slot velocity of the candles is unlikely to draw ichthyoplankton towards the intake unless they are within a foot or less of the filters. Also, video observations of gelatinous particles (about 4 mm in diameter) passing by the Filtrex candles demonstrated that they were not drawn towards the candles when passing within several inches of the candle tops at a channel velocity of about 1.5 ft/s.

Laboratory studies are typically the first step in determining the ability of a fish protection technology to effectively reduce entrainment and impingement of ichthyoplankton at a water intake. The fate of eggs and larvae exposed to a technology can be closely monitored under controlled conditions and multiple parameters can be tested, if needed, with little effort. The results of the Filtrex lab study have provided valuable data on the ability of this technology to effectively protect American shad and river herring ichthyoplankton at the TRDP intake. The results support the conclusion that impingement rates of eggs and larger larvae (> 5 mm) exposed to the Filtrex Filter system will likely be low and that entrainment will not occur for any life stage of ichthyoplankton. Also, ichthyoplankton that pass by the intake filters without impinging should have high survival rates. Survival of impinged organisms may be low, particularly for larvae, but because only a small portion of the entire population will encounter the intake and an even smaller portion will become impinged, the overall impact of impingement mortality should be minimal.

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Electric Power Research Institute (EPRI). 2004. Laboratory Evaluations of an Aquatic Filter Barrier (AFB) for Protecting Early Life Stages of Fish. Prepared by Alden Research Laboratory, Inc., EPRI Report No. 1005534.

TABLE 1. Mean larval length and head capsule depth and mean egg diameter for each species and life stage evaluated with the Filtrex candles. Larval stages include yolk-sac larvae (YSL) and post yolk-sac larvae (PYSL).

Species	Life Stage	Date Tested	*N*	Mean (SD) Larval Length/ Egg Diameter (mm)	Mean (SD) Larval Head Capsule Depth (mm)
American Shad	egg	6/7, 8	30	3.1 (0.10)	--
	PYSL	6/19	30	10.2 (0.54)	1.0 (0.15)
alewife	YSL	6/12, 13	30	3.9 (0.10)	0.6 (0.05)
blueback herring	egg	6/21	30	1.1 (0.05)	--
	PYSL	7/2	30	5.6 (0.27)	0.5 (0.04)
		7/10	20	6.7 (0.47)	0.7 (0.06)
		7/11	30	6.9 (0.46)	0.7 (0.10)

TABLE 2. Collection efficiency data for trials with American shad eggs and post yolk-sac larvae (PYSL). Collection locations are downstream net (DSN) and impingement collection screen (ICS).

Life Stage	Trial Duration (min)	Approach Velocity (ft/s)	Release Location	Collection Location	Number Released	Number Recovered		Percent Recovered
						Live	Dead	
egg	14	1.50	downstream	DSN	100	96	3	99
	2	0.25	between candles and ICS	ICS	100	99	0	99
PYSL	14	1.10	downstream	DSN	100	77	22	99
	2	0.25	between candles and ICS	ICS	100	99	0	99

TABLE 3. Adjusted downstream and impingement collection estimates and mean impingement rates (± 95% CL) for American shad eggs and post yolk-sac larvae. The number of eggs/larvae collected downstream and impinged were adjusted using collection efficiency estimates for each recovery location (downstream net and impingement collection screen). After adjusting for collection efficiency, if the total recovered (downstream and impinged combined) exceeded the number released, the number recovered downstream was capped so that the total recovered equaled the total released.

Life Stage	Mean (SD) Length/ Diameter (mm)	Water Clarity	No. of Trials	Total Released	Adjusted Total Collected Downstream	Adjusted Total Impinged	Adjusted Mean Percent Impinged (95% CL)
egg	3.1 (0.10)	clear	4	400	370	30	7.4 (3.4 – 12.9)
PSYL	10.2 (0.54)	clear	3	300	269	31	10.1 (1.3 – 25.5)

TABLE 4. Survival rates for American shad eggs. Collection locations are downstream net (DSN) and impingement collection screen (ICS) with no filter flow (NF). Trial types are impingement (I), control (C), and handling control (HC). Downstream net controls were released between the candles and the net and impingement collection screen controls were released between the candles and the screen with the filter flow off. Survival rates include hatched larvae and live eggs. Total Survival is calculated by multiplying immediate survival by 48-hr survival.

Collection Location	Trial Type	Total Recovered	Immediate Live	48-hr Hatched	48-hr Live	48-hr Dead	Immediate Survival (%)	48-hr Survival (%)	Total Survival (%)
DSN	I	367	364	145	105	115	99.2	68.7	68.1
DSN	C	99	96	39	0	65	97.0	40.6	39.4
ICS - NF	I	22	22	16	4	2	100.0	90.9	90.9
ICS	C	99	99	96	2	1	100.0	99.0	99.0
--	HC	--	--	62	33	5	--	95.0	95.0

TABLE 5. Survival rates for American shad larvae. Collection locations are downstream net (DSN) and impingement collection screen (ICS) with no filter flow (NF). Trial types are impingement (I), control (C), and handling control (HC). Downstream net controls were released between the candles and the net; impingement collection screen controls were released between the candles and the screen with the filter flow off. Total Survival is calculated by multiplying immediate survival by 48-hr survival.

Collection Location	Trial Type	Total Recovered	Immediate Live	48-hr Live	48-hr Dead	Immediate Survival (%)	48-hr Survival (%)	Total Survival (%)
DSN	I	272	31	1	30	11.4	3.2	0.4
DSN	C	99	0	--	--	--	--	0.0
ICS - NF	I	8	0	--	--	0.0	--	0.0
ICS - BF	I	9	0	--	--	0.0	--	0.0
ICS	C	99	77	10	67	77.8	13.0	10.1
--	HC	--	--	73	27	--	73.0	73.0

TABLE 6. Collection efficiency data for trials with blueback herring eggs. Collection locations are downstream net (DSN) and impingement collection screen (ICS).

Water Clarity	Trial Duration (min)	Approach Velocity (ft/s)	Release Location	Recovery Location	Number Released	Number Recovered		Percent Recovered
						Live	Dead	
clear	14	1.10	downstream	DSN	100	--	--	96
	2	0.25	between candles and ICS	ICS	100	96	3	99
turbid	14	1.10	downstream	DSN	100	--	--	79
	2	0.25	between candles and ICS	ICS	100	83	1	84

TABLE 7. Adjusted downstream and impingement collection estimates and mean impingement rates (95% CI) for blueback herring eggs. The number of eggs collected downstream and impinged were adjusted using collection efficiency estimates for each recovery location (downstream net and impingement collection screen). After adjusting for collection efficiency, if the total recovered (downstream and impinged combined) exceeded the number released, the number recovered downstream was capped so that the total recovered equaled the total released.

Water Clarity	No. of Trials	Total Released	Adjusted Total Collected Downstream	Adjusted Total Impinged	Adjusted Mean Percent Impinged (95% CI)
clear	3	300	275	25	7.8 (0.2 – 24.6)
turbid	3	300	282	18	5.8 (1.3 – 13.1)

TABLE 8. Survival rates for blueback herring eggs tested with clear and turbid water. Collection locations are downstream net (DSN) and impingement collection screen (ICS) with no filter flow (NF). Trial types are impingement (I), control (C), and handling control (HC). Downstream net controls were released between the candles and the net; impingement collection screen controls were released between the candles and the screen with the filter flow off. Total Survival is calculated by multiplying immediate survival by 48-hr survival. Survival data was not recorded for downstream net controls (i.e., only collection efficiency numbers were recorded).

Collection Location	Trial Type	Total Recovered	Immediate Live	48-hr Hatched	48-hr Live	48-hr Dead	Immediate Survival (%)	48-hr Survival (%)	Total Survival (%)
				CLEAR WATER TRIALS					
DSN	I	264	251	15	233	3	95.1	98.8	93.9
DSN	C	96	--	--	--	--	--	--	--
ICS - NF	I	1	1	0	0	1	100.0	0.0	0.0
ICS - BF	I	9	9	0	7	2	100.0	77.8	77.8
ICS	C	99	96	5	79	12	97.0	87.5	84.8
--	HC	--	--	37	50	13	--	87.0	87.0
				TURBID WATER TRIALS					
DSN	I	249	235	19	208	4	94.4	96.6	91.2
DSN	C	79	--	--	--	--	--	--	--
ICS - NF	I	2	1	0	1	0	50.0	100.0	50.0
ICS - BF	I	9	8	0	7	1	88.9	87.5	77.8
ICS	C	84	83	2	79	2	98.8	97.6	96.4
--	HC	--	--	37	50	13	--	87.0	87.0

TABLE 9. Collection efficiency data for trials with alewife yolk-sac larvae. Collection locations are downstream net (DSN) and impingement collection screen (ICS).

Trial Duration (min)	Approach Velocity (ft/s)	Filter Flow	Release Location	Recovery Location	Number Released	Number Recovered		Percent Recovered
						Live	Dead	
14	1.10	off	downstream	DSN	100	0	96	96
2	0.25	off	between candles and ICS	ICS	100	100	0	100
14	1.10	off	upstream of candles	DSN	100	18	48	66
14 2	1.10 0.25	off back flush	upstream of candles	DSN	100	4	74	78
14	1.10	back flush	upstream of candles	DSN	100	0	92	92

TABLE 10. Collection efficiency data for trials with blueback herring post yolk-sac larvae. Collection locations are downstream net (DSN) and impingement collection screen (ICS).

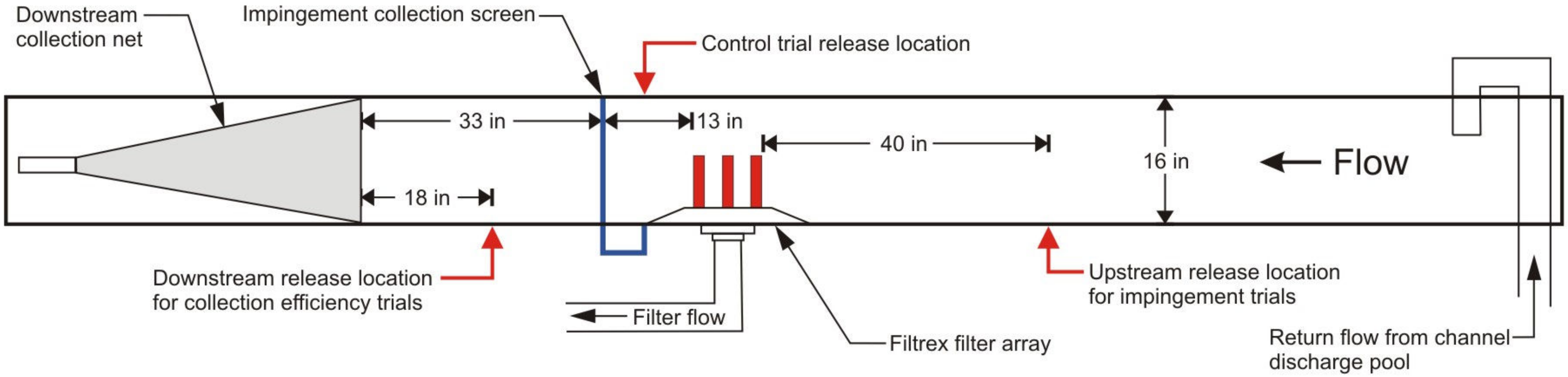
Mean Length (mm)	Water Clarity	Trial Duration (min)	Approach Velocity (ft/s)	Release Location	Recovery Location	Number Released	Number Recovered		Percent Recovered
							Live	Dead	
5.6 mm	clear	14	1.10	downstream	DSN	100	0	98	98
		2	0.25	between candles and ICS	ICS	100	27	55	82
6.7 mm	clear	14	1.10	downstream	DSN	100	0	99	99
		2	0.25	between candles and ICS	ICS	100	35	62	97
6.9 mm	turbid	14	1.10	downstream	DSN	100	0	102	102
		2	0.25	between candles and ICS	ICS	100	36	56	92

TABLE 11. Adjusted downstream and impingement collection estimates and mean impingement rates (95% CI) for alewife and blueback herring larvae. The number of larvae collected downstream and impinged were adjusted using collection efficiency estimates for each recovery location (downstream net and impingement collection screen). After adjusting for collection efficiency, if the total recovered (downstream and impinged combined) exceeded the number released, the number recovered downstream was capped so that the total recovered equaled the total released.

Species	Life Stage	Mean (SD) Length/ Diameter (mm)	Water Clarity	No. of Trials	Total Released	Adjusted Total Collected Downstream	Adjusted Total Impinged	Adjusted Mean Percent Impinged (95% CI)
alewife	YSL	3.9 (0.10)	clear	3	300	126	174	58.1 (37.0 – 77.7)
blueback	PSYL	5.6 (0.27)	clear	3	300	254	46	15.3 (11.2 – 19.9)
blueback	PSYL	6.7 (0.47)	clear	3	300	264	36	11.1 (0.2 – 35.4)
blueback	PSYL	6.9 (0.46)	turbid	3	300	260	40	13.1 (3.8 – 26.9)

TABLE 12. Survival rates for alewife and blueback herring larvae tested with clear and turbid water. Collection locations are downstream net (DSN) and impingement collection screen (ICS) with no filter flow (NF). Trial types are impingement (I), control (C), and handling control (HC). Downstream net controls were released between the candles and the net; impingement collection screen controls were released between the candles and the screen with the filter flow off. Total Survival is calculated by multiplying immediate survival by 48-hr survival. A handling control trial was not conducted for alewife larvae.

Collection Location	Trial Type	Total Recovered	Immediate Live	48-hr Live	48-hr Dead	Immediate Survival (%)	48-hr Survival (%)	Total Survival (%)
				ALEWIFE YOLK-SAC LARVAE - CLEAR WATER TRIALS				
DSN	I	121	2	0	2	1.7	0.0	0.0
DSN	C	96	0	--	--	0.0	--	0.0
ICS - NF	I	6	2	2	0	33.3	100.0	33.3
ICS - BF	I	27	0	0	0	0.0	--	0.0
ICS	C	100	100	99	1	100.0	99.0	99.0
				BLUEBACK HERRING POST YOLK-SAC LARVAE (5.6 MM) - CLEAR WATER TRIALS				
DSN	I	249	0	--	--	0.0	--	0.0
DSN	C	98	0	--	--	0.0	--	0.0
ICS - NF	I	1	0	--	--	0.0	--	0.0
ICS - BF	I	15	0	--	--	0.0	--	0.0
ICS	C	82	27	4	23	32.9	14.8	4.9
--	HC	--	--	65	35	--	65.0	65.0
				BLUEBACK HERRING POST YOLK-SAC LARVAE (6.7 MM) - CLEAR WATER TRIALS				
DSN	I	367	0	--	--	0.0	--	0.0
DSN	C	99	0	--	--	0.0	--	0.0
ICS - NF	I	367	0	--	--	0.0	--	0.0
ICS - BF	I	367	0	--	--	0.0	--	0.0
ICS	C	97	35	23	12	36.1	65.7	23.7
--	HC	--	--	84	16	--	84.0	84.0
				BLUEBACK HERRING POST YOLK-SAC LARVAE (6.9 MM) - TURBID WATER TRIALS				
DSN	I	260	0	--	--	0.0	--	0.0
DSN	C	102	0	--	--	0.0	--	0.0
ICS - NF	I	0	0	--	--	0.0	--	0.0
ICS - BF	I	6	0	--	--	0.0	--	0.0
ICS	C	92	36	29	7	39.1	80.6	31.5
--	HC	--	--	89	11	--	89.0	89.0



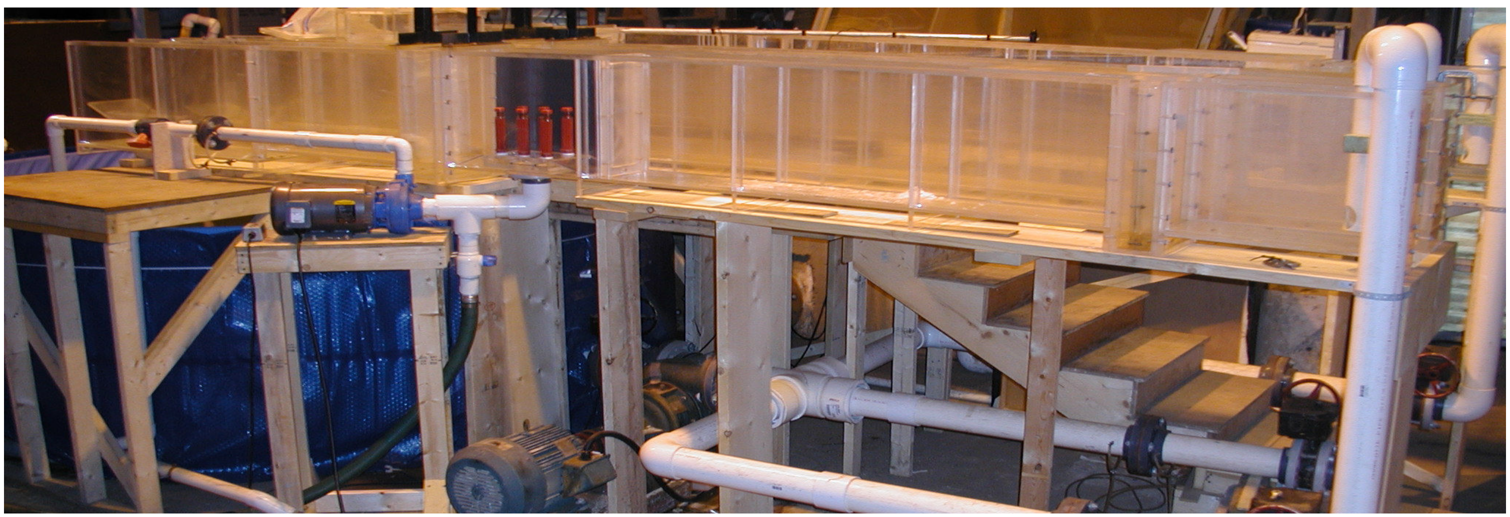


FIGURE 1. Schematic and photograph of Filtrex test facility with approximate distances between facility components and egg and larvae release and collection locations.

APPENDIX A
Impingement Trial Data

TABLE A-1. Summary of impingement trial results for American shad eggs and post yolk-sac larvae (PYSL). All American shad trials were conducted with clear water. The channel velocity for egg trials was 1.5 ft/s and for larvae it was 1.1 ft/s. One hundred (100) eggs/larvae were released for each trial. Eggs and larvae collected in the downstream net while the impingement collection screen was removed between samples with the filter flow off and after back flushing were recorded as impingements recovered with the filter flow off.

Life Stage	Mean (SD) Diameter/ Length (mm)	Trial	Recovered Downstream		Impinged w/Filter Flow Off		Impinged w/Back flush		Total Impinged	Total Recovered
			Live	Dead	Live	Dead	Live	Dead		
egg	3.1 (0.10)	1	93	0	3	0	0	0	3	96
		2	87	1	8	0	0	0	8	96
		3	95	0	5	0	0	0	5	100
		4	89	2	6	0	0	0	6	97
		Total	**364**	**3**	**23**	**0**	**0**	**0**	**22**	**390**
PYSL	10.2 (0.54)	1	4	82	0	5	0	2	7	93
		2	3	95	0	4	0	1	5	103
		3	24	64	0	7	0	6	13	101
		Total	**31**	**241**	**0**	**16**	**0**	**9**	**25**	**297**

TABLE A-2. Summary of impingement trial results for river herring. All trials were conducted with a channel velocity 1.1 ft/s. One hundred (100) eggs/larvae were released for each trial. Larval life stages are yolk-sac (YSL) and post yolk-sac (PSLY).

	Life	Mean (SD)	Water		Recovered		Impinged		Impinged		Total	Total
Species	**Stage**	**Length/**	**Clarity**	**Trial**	**Live**	**Dead**	**Live**	**Dead**	**Live**	**Dead**	**Impinged**	**Recovered**
blueback	egg	1.1 (0.05)	clear	1	82	5	1	0	4	0	5	92
				2	76	8	1	0	4	0	5	89
				3	93	0	0	0	1	0	1	94
				Total	**251**	**13**	**2**	**0**	**9**	**0**	**11**	**275**
blueback	egg	1.1 (0.05)	turbid	1	80	3	0	0	5	0	5	88
				2	71	11	3	1	2	1	7	89
				3	84	0	1	1	1	0	3	87
				Total	**235**	**14**	**4**	**2**	**8**	**1**	**15**	**264**
alewife	YSL	3.9 (0.10)	clear	1	0	33	0	4	0	11	15	48
				2	2	37	0	1	0	5	6	45
				3	0	49	2	7	0	11	20	69
				Total	**2**	**119**	**2**	**12**	**0**	**27**	**41**	**162**
blueback	PYSL	5.6 (0.27)	clear	1	0	84	0	1	0	3	4	88
				2	0	84	0	3	0	4	7	91
				3	0	81	0	1	0	8	9	90
				Total	**0**	**249**	**0**	**5**	**0**	**15**	**20**	**269**
blueback	PYSL	6.7 (0.47)	clear	1	0	84	0	6	0	6	12	96
				2	0	95	0	2	0	2	4	99
				3	0	85	0	10	0	6	16	101
				Total	**0**	**264**	**0**	**18**	**0**	**14**	**32**	**296**
blueback	PYSL	6.9 (0.46)	Turbid	1	0	81	0	1	0	2	3	84
				2	0	90	0	0	0	1	1	91
				3	0	89	0	1	0	3	4	93
				Total	**0**	**260**	**0**	**2**	**0**	**6**	**8**	**268**

APPENDIX B
Survival Data

TABLE B-1. American shad egg impingement and control survival data. Collection locations are downstream net (DSN), impingement collection screen (ICS), and handling control (HC; i.e., eggs/larvae placed in beaker and held for 48 hours). No eggs were collected from the impingement collection screen after the filter candles were back flushed (i.e., all eggs collected from this screen were impingements released when the filter flow was shut off).

Trial Type	Collection Location	Trial	Total Recovered	Immediate Live	48-hr Hatched	48-hr Live	48-hr Dead	Immediate Survival (%)	48-hr Survival (%)	Total Survival (%)
Impingement	DSN	1	93	93	5	55	33	100.0	64.5	64.5
		2	88	87	43	9	40	98.9	59.8	59.1
		3	95	95	72	14	6	100.0	90.5	90.5
		4	91	89	25	27	36	97.8	58.4	57.1
		Total	**367**	**364**	**145**	**105**	**115**	**99.2**	**68.7**	**68.1**
Impingement	ICS	1	3	3	2	1	0	100.0	100.0	100.0
		2	8	8	6	1	1	100.0	87.5	87.5
		3	5	5	5	0	0	100.0	100.0	100.0
		4	6	6	3	2	1	100.0	83.3	83.3
		Total	**22**	**22**	**16**	**4**	**2**	**100.0**	**90.9**	**90.9**
Control	DSN	1	99	96	39	0	65	97.0	40.6	39.4
	ICS	1	99	99	96	2	1	100.0	99.0	99.0
	HC	1	--	--	62	33	5	--	95.0	95.0

TABLE B-2. American shad post yolk-sac larvae impingement and control survival data. Collection locations are downstream net (DSN), impingement collection screen (ICS) with no filter flow (NF) and back flushing (BF), and handling control (HC; i.e., eggs/larvae placed in beaker and held for 48 hours). For impingement trials, survival data for eggs collected from the impingement collection screen with the filter flow off and during back flushing were combined.

Trial Type	Collection Location	Trial	Total Recovered	Immediate Live	48-hr Live	48-hr Dead	Immediate Survival (%)	48-hr Survival (%)	Total Survival (%)
Impingement	DSN	1	86	4	0	4	4.7	0.0	0.0
		2	98	3	1	2	3.1	33.3	1.0
		3	88	24	0	24	27.3	0.0	0.0
		Total	**272**	**31**	**1**	**30**	**11.4**	**3.2**	**0.4**
Impingement	ICS - NF	1	3	0	--	--	0.0	--	0.0
		2	3	0	--	--	0.0	--	0.0
		3	2	0	--	--	0.0	--	0.0
		Total	**8**	**0**	**--**	**--**	**0.0**	**--**	**0.0**
Impingement	ICS - BF	1	2	0	--	--	0.0	--	0.0
		2	1	0	--	--	0.0	--	0.0
		3	6	0	--	--	0.0	--	0.0
		Total	**9**	**0**	**--**	**--**	**0.0**	**--**	**0.0**
Control	DSN	1	99	0	--	--	--	--	0.0
	ICS	1	99	77	10	67	77.8	13.0	10.1
	HC	1	--	--	73	27	--	73.0	73.0

TABLE B-3. Blueback herring egg impingement and control survival data for clear water tests. Collection locations are downstream net (DSN), impingement collection screen (ICS) with no filter flow (NF) and back flushing (BF), and handling control (HC; i.e., eggs/larvae placed in beaker and held for 48 hours).

Trial Type	Collection Location	Trial	Total Recovered	Immediate Live	48-hr Hatched	48-hr Live	48-hr Dead	Immediate Survival (%)	48-hr Survival (%)	Total Survival (%)
Impingement	DSN	1	87	82	5	75	2	94.3	97.6	92.0
		2	84	76	5	70	1	90.5	98.7	89.3
		3	93	93	5	88	0	100.0	100.0	100.0
		Total	**264**	**251**	**15**	**233**	**3**	**95.1**	**98.8**	**93.9**
Impingement	ICS - NF	1	1	1	0	0	1	100.0	0.0	0.0
		2	0	0	--	--	--	0.0	--	0.0
		3	0	0	--	--	--	0.0	--	0.0
		Total	**1**	**1**	**0**	**0**	**1**	**100.0**	**0.0**	**0.0**
Impingement	ICS - BF	1	4	4	0	4	0	100.0	100.0	100.0
		2	4	4	0	3	1	100.0	75.0	75.0
		3	1	1	0	0	1	100.0	0.0	0.0
		Total	**9**	**9**	**0**	**7**	**2**	**100.0**	**77.8**	**77.8**
Control	DSN	1	96	*No mortality or survival data recorded for this group*						
	ICS	1	99	96	5	79	12	97.0	87.5	84.8
	HC	1	--	--	37	50	13	--	87.0	87.0

TABLE B-4. Blueback herring egg impingement and control survival data for turbid water tests. Collection locations are downstream net (DSN), impingement collection screen (ICS) with no filter flow (NF) and back flushing (BF), and handling control (HC; i.e., eggs/larvae placed in beaker and held for 48 hours).

Trial Type	Collection Location	Trial	Total Recovered	Immediate Live	48-hr Hatched	48-hr Live	48-hr Dead	Immediate Survival (%)	48-hr Survival (%)	Total Survival (%)
Impingement	DSN	1	83	80	1	77	0	96.4	97.5	94.0
		2	82	71	15	52	3	86.6	94.4	81.7
		3	84	84	3	79	1	100.0	97.6	97.6
		Total	**249**	**235**	**19**	**208**	**4**	**94.4**	**96.6**	**91.2**
Impingement	ICS - NF	1	0	0	--	--	--	0.0	--	0.0
		2	0	0	--	--	--	0.0	--	0.0
		3	2	1	0	1	0	50.0	100.0	50.0
		Total	**2**	**1**	**0**	**1**	**0**	**50.0**	**100.0**	**50.0**
Impingement	ICS - BF	1	5	5	0	5	0	100.0	100.0	100.0
		2	3	2	0	1	1	66.7	50.0	33.3
		3	1	1	0	1	0	100.0	100.0	100.0
		Total	**9**	**8**	**0**	**7**	**1**	**88.9**	**87.5**	**77.8**
Control	DSN	1	79	*No mortality or survival data recorded for this group*						
	ICS	1	84	83	2	79	2	98.8	97.6	96.4
	HC	1	--	--	37	50	13	--	87.0	87.0

TABLE B-5. Alewife yolk-sac larvae impingement and control survival data for clear water tests. Collection locations are downstream net (DSN), impingement collection screen (ICS) with no filter flow (NF) and back flushing (BF), and handling control (HC; i.e., eggs/larvae placed in beaker and held for 48 hours).

Trial Type	Collection Location	Trial	Total Recovered	Immediate Live	48-hr Live	48-hr Dead	Immediate Survival (%)	48-hr Survival (%)	Total Survival (%)
Impingement	DSN	1	33	0	--	--	0.0	--	0.0
		2	39	2	0	2	5.1	0.0	0.0
		3	49	0	--	--	0.0	--	0.0
		Total	**121**	**2**	**0**	**2**	**1.7**	**0.0**	**0.0**
Impingement	ICS - NF	1	1	0	--	--	0.0	--	0.0
		2	0	0	--	--	0.0	--	0.0
		3	5	2	2	0	40.0	100.0	40.0
		Total	**6**	**2**	**2**	**0**	**33.3**	**100.0**	**33.3**
Impingement	ICS - BF	1	11	0	--	--	0.0	--	0.0
		2	5	0	--	--	0.0	--	0.0
		3	11	0	--	--	0.0	--	0.0
		Total	**27**	**0**	**0**	**0**	**0.0**	**--**	**0.0**
Control	DSN	1	96	0	--	--	0.0	--	0.0
	ICS	1	100	100	99	1	100.0	99.0	99.0
	HC	1	*No handling control conducted for this species and life stage*						

TABLE B-6. Blueback herring post yolk-sac larvae impingement and control survival data for clear water tests. Mean larval length was 5.6 mm. Collection locations are downstream net (DSN), impingement collection screen (ICS) with no filter flow (NF) and back flushing (BF), and handling control (HC; i.e., eggs/larvae placed in beaker and held for 48 hours).

Trial Type	Collection Location	Trial	Total Recovered	Immediate Live	48-hr Live	48-hr Dead	Immediate Survival (%)	48-hr Survival (%)	Total Survival (%)
Impingement	DSN	1	84	0	--	--	0.0	--	0.0
		2	84	0	--	--	0.0	--	0.0
		3	81	0	--	--	0.0	--	0.0
		Total	**249**	**0**	**--**	**--**	**0.0**	**--**	**0.0**
Impingement	ICS - NF	1	0	0	--	--	0.0	--	0.0
		2	0	0	--	--	0.0	--	0.0
		3	1	0	--	--	0.0	--	0.0
		Total	**1**	**0**	**--**	**--**	**0.0**	**--**	**0.0**
Impingement	ICS - BF	1	3	0	--	--	0.0	--	0.0
		2	4	0	--	--	0.0	--	0.0
		3	8	0	--	--	0.0	--	0.0
		Total	**15**	**0**	**--**	**--**	**0.0**	**--**	**0.0**
Control	DSN	1	98	0	--	--	0.0	--	0.0
	ICS	1	82	27	4	23	32.9	14.8	4.9
	HC	1	--	--	65	35	--	65.0	65.0

TABLE B-7. Blueback herring post yolk-sac larvae impingement and control survival data for clear water tests. Mean larval length was 6.7 mm. Collection locations are downstream net (DSN), impingement collection screen (ICS) with no filter flow (NF) and back flushing (BF), and handling control (HC; i.e., eggs/larvae placed in beaker and held for 48 hours).

Trial Type	Collection Location	Trial	Total Recovered	Immediate Live	48-hr Live	48-hr Dead	Immediate Survival (%)	48-hr Survival (%)	Total Survival (%)
Impingement	DSN	1	84	0	--	--	0.0	--	0.0
		2	95	0	--	--	0.0	--	0.0
		3	85	0	--	--	0.0	--	0.0
		Total	**264**	**0**	**--**	**--**	**0.0**	**--**	**0.0**
Impingement	ICS - NF	1	3	0	--	--	0.0	--	0.0
		2	2	0	--	--	0.0	--	0.0
		3	6	0	--	--	0.0	--	0.0
		Total	**11**	**0**	**--**	**--**	**0.0**	**--**	**0.0**
Impingement	ICS - BF	1	6	0	--	--	0.0	--	0.0
		2	2	0	--	--	0.0	--	0.0
		3	6	0	--	--	0.0	--	0.0
		Total	**14**	**0**	**--**	**--**	**0.0**	**--**	**0.0**
Control	DSN	1	99	0	--	--	0.0	--	0.0
	ICS	1	97	35	23	12	36.1	65.7	23.7
	HC	1	--	--	84	16	--	84.0	84.0

TABLE B-8. Blueback herring post yolk-sac larvae impingement and control survival data for turbid water tests. Mean larval length was 6.9 mm. Collection locations are downstream net (DSN), impingement collection screen (ICS) with no filter flow (NF) and back flushing (BF), and handling control (HC; i.e., eggs/larvae placed in beaker and held for 48 hours).

Trial Type	Collection Location	Trial	Total Recovered	Immediate Live	48-hr Live	48-hr Dead	Immediate Survival (%)	48-hr Survival (%)	Total Survival (%)
Impingement	DSN	1	81	0	--	--	0.0	--	0.0
		2	90	0	--	--	0.0	--	0.0
		3	89	0	--	--	0.0	--	0.0
		Total	**260**	**0**	**--**	**--**	**0.0**	**--**	**0.0**
Impingement	ICS - NF	1	0	0	--	--	0.0	--	0.0
		2	0	0	--	--	0.0	--	0.0
		3	0	0	--	--	0.0	--	0.0
		Total	**0**	**0**	**--**	**--**	**0.0**	**--**	**0.0**
Impingement	ICS - BF	1	2	0	--	--	0.0	--	0.0
		2	1	0	--	--	0.0	--	0.0
		3	3	0	--	--	0.0	--	0.0
		Total	**6**	**0**	**--**	**--**	**0.0**	**--**	**0.0**
Control	DSN	1	102	0	--	--	0.0	--	0.0
	ICS	1	92	36	29	7	39.1	80.6	31.5
	HC	1	--	--	89	11	--	89.0	89.0