LABORATORY EVALUATION OF LARVAL FISH IMPINGEMENT AND DIVERSION SYSTEMS

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ABSTRACT

From 1978 to 1980, laboratory studies were conducted to determine the impingement survival and diversion capabilities of larval fish. The effect on survival of other components of impingement and diversion systems, including air exposure, spraywashing and pumping, was also investigated. For the Empire State Electric Energy Research Corporation (ESEERCO0), larval striped bass, alewife, winter flounder, and yellow perch were subjected to testing in all eight models constructed for these studies. In 1979, Northern States Power Company (NSP) sponsored a single impingement survival study with walleye, channel catfish, and bluegill. Results of these studies are presented in two parts.

Relative to impingement survival, survival data for all seven test species are presented. Tests were conducted at approach flow velocities and impingement durations ranging from 15.2 to 91 cm/sec and two to 16 minutes, respectively. In addition, quantitative and qualitative results of screen retention studies (to determine the mesh size required to retain larvae), air exposure studies, and evaluations of the effectiveness of different spraywash systems in removing impinged larvae are presented.

With respect to larval diversion efficiency, the ability of striped bass, winter flounder, alewife, and yellow perch to guide along an angled, fine-mesh screen to a bypass was investigated for ESEERCO. The data obtained indicate that selected larvae are capable of active diversion at a relatively early age.

Since diversion systems do not elevate bypassed organisms, applications of such systems require that energy be supplied to return these organisms to source water body. Accordingly, two types of pumps (jet and screw-impeller, centrifugal pumps) were studied. Data from the diversion and pump studies are presented.

INTRODUCTION

From 1978 to 1980, studies were conducted by Stone & Webster Engineering Corporation and Alden Research Laboratory for the Empire State Electric Energy Research Corporation (ESEERCO) to investigate fine-mesh screening systems which might act to mitigate entrainment losses of fish larvae at power plant intakes. The objective of the larval studies was to investigate several components of fine-mesh screening systems to determine their potential for

collecting, diverting, or transporting larvae of several fish species with low resultant mortality. These systems included:

1. Modified, traveling water screens with fine-mesh screening, lifting buckets, and low-pressure sprays.
2. Angled, traveling water screens with fine-mesh material and a bypass.
3. Pumping units which can be required to return collected or diverted larvae to their natural environment.

Species tested included striped bass (*Morone saxatilis*), winter flounder (*Pseudopleuronectes americanus*), alewife (*Alosa pseudoharengus*), and yellow perch (*Perca flavescens*).

In 1979, Northern States Power Company (NSP) sponsored an impingement survival study to investigate the potential effectiveness of a modified, traveling screen system for use at a power plant on the Mississippi River in Minnesota. This study was conducted concurrently with 1979 ESEERCO studies and included testing with walleye (*Stizostedion vitreum*), channel catfish (*Ictalurus punctatus*) and bluegill (*Lepomis macrochirus*).

The concept of utilizing modified traveling water screens for collecting and removing organisms from an intake flow presently affords a relatively inexpensive and potentially effective method for protecting all life stages of fish at power plants. This impingement concept requires modifications for the protection of larvae including the incorporation of fine-mesh screening material, the addition of lifting buckets which will provide water for the organisms when the screen panels are removed from the flow, and the use of low pressure to wash the organisms into a sluiceway with minimal damage.

The limited research which had been previously conducted on the larval impingement concept indicated that several factors were of importance relative to obtaining acceptable survival. First, the velocity and duration of impingement on a screen influences survival. It has been found that the ability of organisms to withstand impingement over time varies widely by species and age. Second, when a traveling screen panel clears the water surface, impinged larvae can be exposed to the air for various lengths of time depending on the screen travel speed. It has been noted that air exposure can seriously affect the survival potential of some species, and this factor should, therefore, be investigated. Finally, the spray-wash system used to remove larvae from the screen and lifting bucket can injure them further, and acceptable spray pressures and orientations must be identified. All of these potential sources of stress associated with the impingement concept were investigated for ESEERCO in the present study. Testing for NSP involved only impingement survival determinations at various velocities and durations of impingement.

In addition to this concept of utilizing fine-mesh traveling screens for the collection and removal of small organisms, limited research has been conducted which indicated that such screens may have the potential for guiding motile organisms, thereby protecting them from entrainment through power plants. Diversion studies with juvenile fish indicated that approach flow velocity is an important factor in guidance efficiency. In attempting to divert fish larvae, it could be assumed that screen mesh size and efficiency would change as larvae grow and gain greater swimming capabilities. Therefore, mesh size and velocity were primary variables of interest during the ESEERCO study. Since diversion screens guide organisms to a bypass without lifting them, energy must be supplied to induce a bypass flow and to transport the organisms back to their natural environment. During the ESEERCO study, two pumps were evaluated for this purpose.

The test facilities and methods employed in conducting each of the studies described above and the results obtained are presented in the following discussions. During the studies, over 3,000 tests were conducted with more than 75,000 larvae of all species combined.

MATERIALS AND METHODS

LARVAL HOLDING FACILITY

All fish larvae were reared and held in a laboratory facility containing numerous holding tanks and aquaria. Striped bass were held in aquaria at approximately 3 ppt salinity and were maintained on a diet of *Artemia* nauplii, supplemented with adult frozen brine shrimp as they grew larger. Winter flounder larvae were hatched in the laboratory from eggs, where held at 15 ppt salinity, and were maintained on a diet of live rotifers (*Brachionus plicatilis*). Alewife and yellow perch were held in a specially designed holding tank connected to a biological filter. These species were maintained on a diet of plankton collected from a local pond. Walleye, bluegill, and channel catfish were also held in the filtered holding tank and were fed *Artemia* nauplii. supplemented with two commercially prepared dry diets.

During the studies, average daily length of each species was determined from a sample of 25 randomly selected individuals. Test and control organisms were handled in the same fashion, except that controls were not subjected to the test treatment.

Following all tests (all models), test and control organisms were placed in aerated, one liter beakers for observation of 96 hour survival and were handled

and fed in an identical manner. Following initial mortality determinations, individual beakers were checked at 24, 48, 72 and 96 hours and all dead larvae were removed and recorded on data sheets. As discussed later, alewife and yellow perch prolarvae were held for 48 hours.

TEST FACILITY DESCRIPTION AND TEST PROCEDURES

Impingement Survival Study

Impingement survival studies were conducted using 355 or 500 micron mesh polyester screens mounted perpendicular to the flow direction in a 30.5 wide test segment as shown in Figures 1 and 2. Two segments (channels) were built into one flume to allow two tests to be performed concurrently. The 355 micron screen was used to ensure retention of the smallest larvae. When the larval length increased and 100 percent retention was obtained on the 355 micron mesh in the screen retention study, a 500 micron screen was utilized.

A clear acrylic frame held the impingement screen for each segment and incorporated a collection bucket. During the tests, the frame was located so that its sides were flush with the side walls of the segment and the collection bucket was recessed into the floor. This provided an unobstructed flow to the impingement screen. Acrylic sections in the sides of the flume allowed observation of the organisms during testing. At the end of a pair of tests, a pneumatic cylinder raised the screen frame from the flow and the larvae were gently washed into the collection bucket.

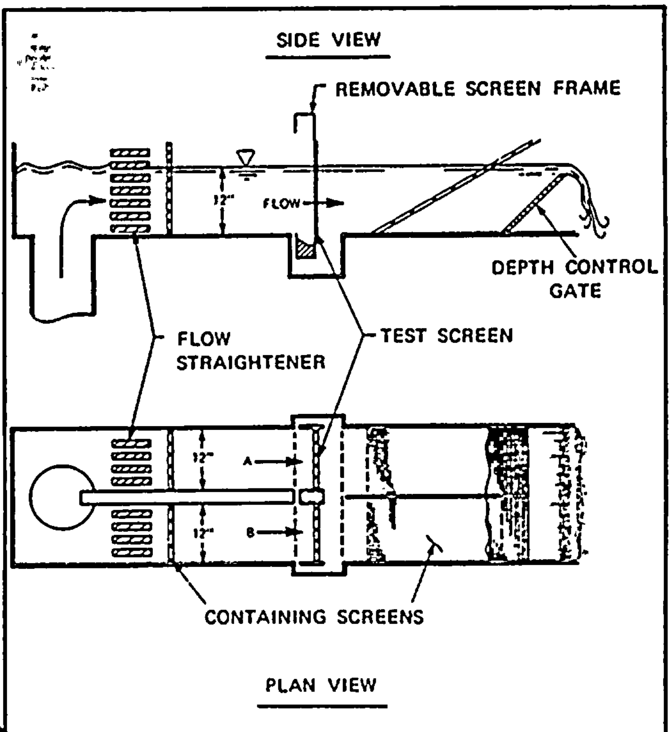


Figure 1. Impingement test facility

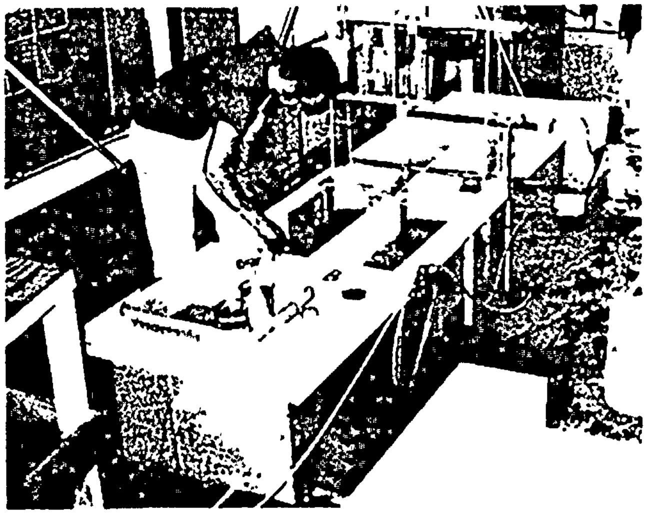


Figure 2. Impingement test facility, test screen in place

Flow entered and exited the test segments through 250 micron containment screens which prevented the loss of any larvae not impinged on the test screen. At the downstream end of the flume, the flow was returned to a sump over a gate that controlled the flow depth.

Except where noted in the results section, the following testing procedures were employed for all test species. Prior to each series of tests, 25 larvae, serving as the control for that series, were taken from the stock tanks and placed in the collection bucket of the impingement facility for 16 minutes (representing the longest duration tested). The larvae were then removed and held for 96 hours to determine latent mortality. In addition, a separate control group, composed of 25 larvae, was removed from the stock holding tanks and placed directly into holding beakers for 96 hours. This control was utilized to separate out mortality arising solely from holding.

At the start of each test, larvae were introduced into the segments upstream of the fine-mesh test screens. Testing consisted of introducing groups of larvae into the flume at velocities of 15.2, 30.5, 45.7, 61.0, or 91.4 cm/sec and allowing them to impinge on the fine-mesh screen panels for durations of two, four, eight, and 16 minutes. Thus, a complete test series involved filling in the following impingement duration/velocity matrix:

Duration	Velocity (cm/sec)				
(min)	15.2	30.5	45.7	61.0	91.4
2	X	X	X	X	X
4	X	X	X	X	X
8	X	X	X	X	X
16	X	X	X	X	X

Analytical results of striped bass data gathered in 1979 clearly indicated that this matrix could be reduced without jeopardizing the quality of the data. Therefore, testing with winter flounder, yellow perch, alewife, walleye, bluegill and channel catfish in 1980 involved use of limited matrices centered on velocity/duration combinations which yielded relatively high survival. This approach eliminated needless replicates of combinations which consistently resulted in high or total mortality. At times, it was necessary to reduce a matrix further than planned due to limitations in the number of organisms available for testing. Matrices were also changed in certain cases when early results indicated that alterations would yield more meaningful data. All changes are presented in the results section.

At the conclusion of each pair of tests, the screens were raised and the larvae which had been impinged were gently washed from the screens into collection buckets. Larvae were then removed from the buckets, enumerated, and placed in holding beakers. Larvae which had been impinged but had escaped from the screens while they were being raised (to be collected on the downstream containment screens) were removed from the facility, but were not held for latent mortality since these organisms experienced prolonged air exposure on the downstream containment screens. In general, very few larvae (on the average, one to two per test) were lost in this fashion.

The beakers containing those larvae which had impinged were placed in the 96-hour holding facility. A count of initially live and dead larvae in the beakers was made approximately one hour after the completion of the test to allow those larvae which had been stunned by impingement time to recover or die. Thereafter, mortality was recorded at 24, 48, 72, and 96 hours. Alewife and yellow perch prolarvae were held for only 48 hours. Since the prolarval stage of both species spans only two to five days, it was necessary to shorten the holding period to avoid influencing test mortalities with natural mortalities which occur during the transition to postlarvae.

At the end of the latent effects holding period, beakers were siphoned down, and the number of live larvae was recorded. Cannibalism among the larvae was observed, but was not a major problem. Missing larvae were generally believed to have been cannibalized. However, in the interest of conservatism, missing larvae were included in the overall test mortality figures.

Screen Retention Study

Testing in 1979 with striped bass was conducted in a small flume with a 7.6 cm square cross-section. Square weave polyester screens of 0.5, 1.0, 1.5 and 2.0 mm mesh were mounted on interchangeable frames which could be individually inserted into the flume perpendicular to the flow at the end of a 30.5 cm long test section. The flume was constructed of clear acrylic to provide visual observation of the larvae during the tests. A 250 micron screen was installed to retain all organisms that were not retained and therefore passed through the test screen.

A centrifugal pump supplied flow to the flume, through a valve which was adjusted to produce the desired velocity. A small propeller meter was used to measure the velocity 1.3 cm upstream of the test screen.

In 1980, the screen retention studies were conducted in an expanded facility comprised of eight parallel channels, thus allowing tests to be run concurrently. The channels were 91 cm long, 11.4 cm wide, and 20.3 cm deep. As shown in Figure 3, the test screens were mounted on interchangeable plastic frames which were positioned in slots in the channel walls and floor. The flow through the screens was not obstructed by the screen frames.

Downstream of the test screens a gate was used to control the flow depth and velocity. A small propeller meter was used to set the flow. Velocity screens were mounted at each end of the channels to prevent the loss of organisms during testing.

In each 1979 striped bass test, 15 larvae were then introduced into the flume operating at a specific

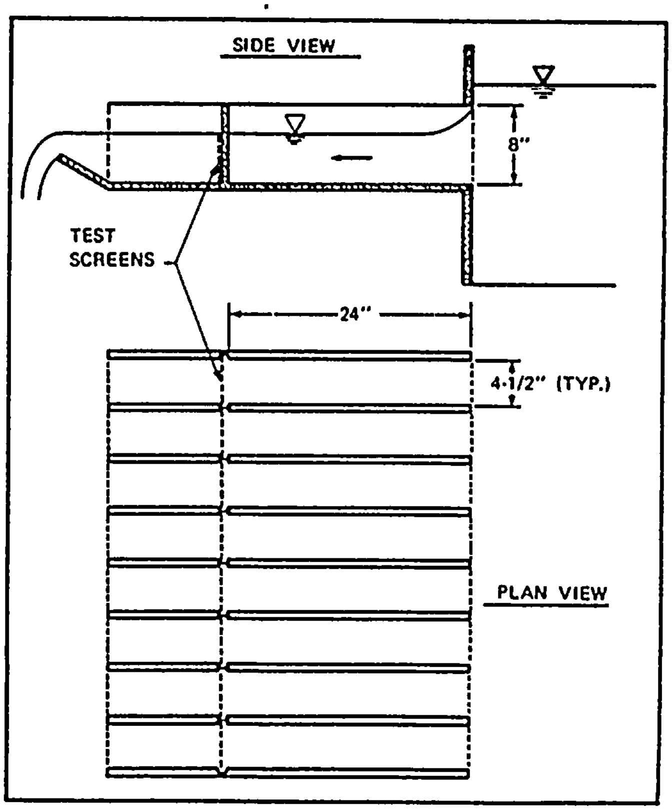


Figure 3. Screen retention facility, 1980

velocity (15.2, 24.4, 30.5, or 45.7 cm/sec) with the appropriate mesh size incorporated (0.5, 1.0, 1.5, or 2.0 mm). Each test was run until all larvae had been impinged or entrained. Maximum test time was approximately 10 minutes.

Observations were made during each test as to the manner in which larvae were impinged or entrained. At the conclusion of each test, all larvae were removed from the flume and enumerated. None were held for latent mortality studies.

In 1980, procedures were modified slightly to make full utilization of the new model described above. Accordingly, in each test with winter flounder, alewife, and yellow perch, 25 larvae were introduced into each channel of the screen retention facility. The facility was operated at one of two velocities (15.2 or 45.7 cm/sec) with appropriate mesh sizes incorporated (0.355, 0.5, 1.0, and 1.5 mm). Eight tests were conducted simultaneously with each lasting approximately five minutes.

At the conclusion of a test, each screen panel was removed from the facility and the larvae which had been impinged were washed into collection beakers and enumerated. Larvae were not held for latent mortality studies.

Air Exposure Study

Twenty-gallon aquaria were used for testing the effects of air exposure on the test larvae. In 1979, one aquarium was utilized to test striped bass. In 1980, two aquaria were used to test winter flounder, alewife, and yellow perch. Ten acrylic cylinders of 11.4 cm diameter were supported in each tank. These cylinders were open at the top and covered with 355 or 500 micron mesh screening at the bottom, such that when the cylinders were removed from the tank, the larvae were retained on the screen and exposed to the air.

For each test, 25 larvae were placed in each of the ten test cylinders. At the start of a test, cylinders 1 through 9 were removed simultaneously from the tank thereby exposing the contained larvae to the air. Cylinder number 10 contained 25 larvae which served as the control for each series of tests. Test larvae were exposed to ambient air for specific durations after which they were returned to the aquarium. Initial mortality was recorded in each cylinder approximately one hour after the conclusion of each test. Thereafter, mortality of striped bass and winter flounder was recorded at 24, 48, 72, and 96 hours. Alewife and yellow perch were held for 48 hours only. The prolarval stage of these species lasts approximately two to five days. To avoid influencing the test results with high natural mortality which occurs during the transition from pro- to postlarval stage, the holding period was necessarily shortened. At the end of 48 or 96 hours, the number of live larvae was recorded for both the test and control cylinders.

Spraywash System Studies

As described below, two spraywash systems were modeled to facilitate testing. Design and operational factors which might influence larval mortality were carefully simulated. Both systems were tested with striped bass juveniles in 1979. However, 1980 testing with flounder, alewife, and yellow perch was limited to one system.

A 30.5 cm wide section of one screen panel was reproduced for the evaluation of each of the spraywash systems. The spray nozzles were fixed in position and a centrifugal pump was used to develop spray pressures of up to 1.1 kg/cm^2 (15 psi) at each nozzle.

The front-wash test facility (Figure 4) was designed using clear acrylic in the shape of the screen and lifting bucket. This spray system is designed to wash larvae from the lifting bucket into a collection trough; therefore, modeling of the screen or its movement was not required. A fixed nozzle was located so that the spray impacted the back of the lifting basket and washed the water over the front lip. A collection area was incorporated to retrieve the larvae after the test.

The back-wash spray test facility (Figure 4) incorporated a 500 micron screen mounted in an acrylic frame. The frame included a lifting bucket at the bottom of the screen and a deflector which modeled the seal between screen panels on an operating traveling screen. The frame was mounted in supports that allowed it to rotate, spilling the contents of the lifting basket onto the screen face. The frame, in the inverted position, could be lowered past a fixed spray nozzle. The water sprayed through the screen

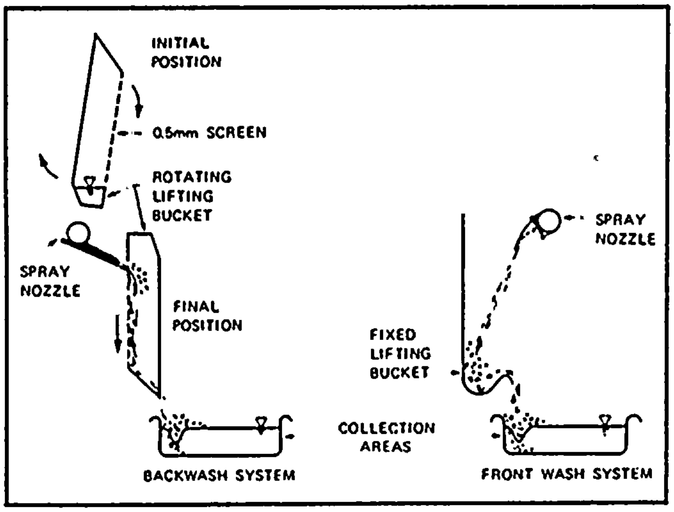


Figure 4. Spray wash test facilities

traveled down the deflector and into a collection area. The entire process reflected the passage of a screen basket over the head shaft of a traveling screen to a rear spraywash removal point.

Since the procedures used for testing the back-wash and front-wash systems differed, they are described separately below.

Front-Wash System. Prior to each series of tests, 20 control larvae were placed in the screen bucket. These larvae were allowed to remain in the bucket for approximately two minutes and were then removed and placed in a holding beaker for 96 hours. In addition, a separate control consisting of 20 larvae was utilized to identify mortality due to handling or temperature differences. These larvae were removed from the stock tanks and were placed directly into holding beakers and held for 96 hours.

At the start of each test, twenty larvae were placed in the lifting bucket of the spraywash test apparatus. The spraywash was then activated and allowed to clean the bucket for approximately five seconds, washing the larvae into the collection trough. Larvae were then removed from the trough and placed in holding beakers for 96 hours. Spraywash pressures of 0.35, 0.7 and 0.84 kg/cm^2 (5, 10, and 12 psi) were evaluated. Initial mortality was recorded approximately one hour after completion of each test. Thereafter, mortality was recorded at 24, 48, 72, and 96 hours. At the end of the 96-hour holding period, the number of live larvae was recorded. The percent mortality was then calculated for each test, as well as for the two control groups.

Back-Wash System. The same control groups used for the front-wash tests were utilized for the back-wash tests since both test series were conducted during the same period. At the start of each test, twenty larvae were introduced into the screen bucket of the spraywash apparatus. The bucket had been previously filled with water. The screen frame was then rotated 180 degrees. Rotation time was about 20 seconds to simulate passage of the screen basket over the head shaft in an actual power plant. As the basket rotated, water and larvae contained in the bucket gently spilled on the mesh. Larvae retained on the mesh were then washed off of the screen into a collection trough. The back-wash spray intercepted the screen at a 45 degree angle, and was operated at a supply pressure of approximately 0.7 kg/cm^2 (10 psi).

Larvae were removed from the collection trough and were placed into holding beakers for 96 hours. Mortalities were recorded in the same manner as with the front-wash tests.

Angled Screen Diversion Study

Larval diversion studies were conducted with six fine-mesh screens mounted on interchangeable aluminum frames. The 2.4 m long screens were located in a 1.2 m wide flume at an angle of 25° to the direction of flow. Each angled screen led to a 15.2 cm wide bypass channel. The test facility is shown in Figures 5 and 6.

A pump recirculated water from a sump through the flume. The flow through the flume was divided such that 87 percent passed through the angled screen while 13 percent passed down the bypass. This flow ratio was established to ensure equal velocity approaching the screen and into the bypass. The flow through the angled screen was filtered through a 250 micron mesh containment screen and returned to the sump over a gate that controlled the flow depth. The bypass flow discharged from the 15.2 cm wide bypass channel into a 1.2 m wide semi-circular collection area. The larger width in this area provided a decrease in velocity before the flow passed through a 250 micron containment screen.

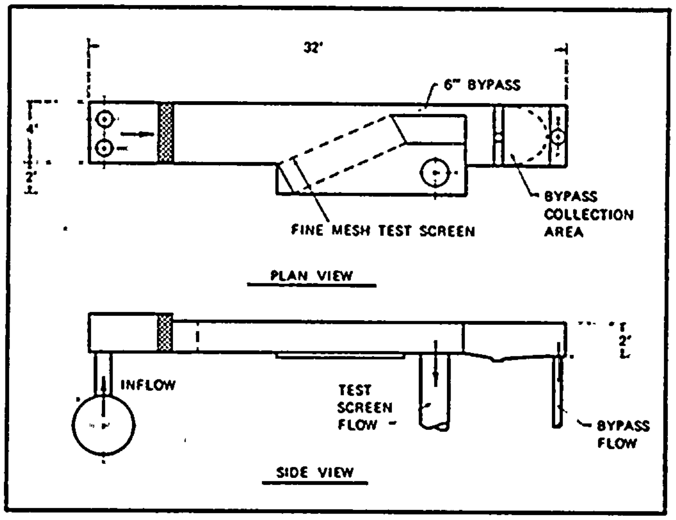


Figure 5. Angled, fine-mesh screen test facility

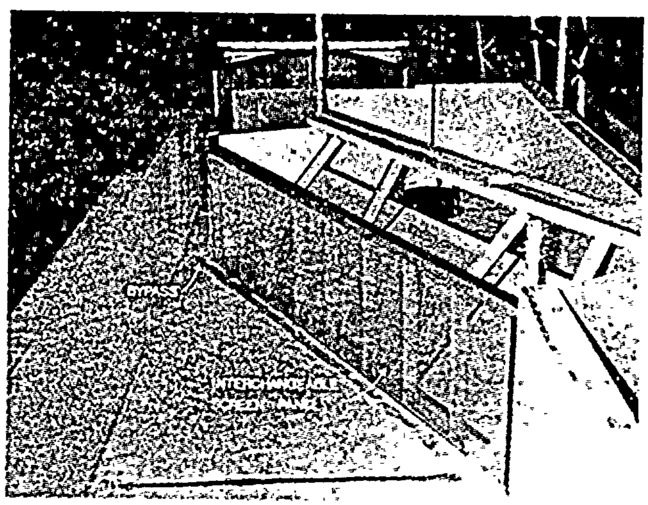


Figure 6. Diversion test facility looking downstream

The lowered velocity minimized the impingement of bypassed organisms and allowed their removal. A second gate behind this containment screen controlled the flowrate through the bypass.

Synthetic and metallic wire screens of 1.5 and 2.5 mm mesh were used in the 1978 study with striped bass. The synthetic materials were woven in square mesh while the metallic material was woven in an oblong mesh and rolled to produce a panel with a flat surface ("smooth-tex"). In the 1979 and 1980 studies, only synthetic square mesh screens were used. Four mesh sizes of 1.0, 4.0, 5.0, and 9.5 mm were tested.

Prior to each test, the flow was established to yield the desired test velocity. The velocity in the bypass was adjusted to equal the velocity in the channel approaching the angled screen. Velocity measurements were taken in the approach and bypass channels to verify conditions.

Test procedures differed slightly between the 1978, 1979, and 1980 angled screen test periods. Therefore, they are discussed below by year.

1978. Striped bass larvae were tested over a period of six weeks during which the larvae grew from approximately six to 19 mm. For each test, the water depth in the flume was adjusted and the approach channel and bypass velocity were set at 15.2 or 30.5 cm/sec. Fifty larvae were then introduced into the flume upstream of the test streen and were tested under the established conditions. Larvae which passed through the screen (entrained) were collected on a 0.25 mm mesh containment screen and were enumerated. Bypassed larvae entered a low velocity collection area where they were contained by another 0.25 mm screen. From here, larvae were removed and placed in 1.0 liter beakers for 96 hour mortality studies. Testing was conducted under light and dark conditions.

All tests were conducted under lighted conditions during the early stages of the study to permit observations of behavior. As the larvae grew, they became able to swim against the current and could, therefore, maintain their positions in the flume for long periods. To facilitate testing, it was necessary to conduct tests in the dark, since larvae moved downstream more rapidly under darkened conditions. Fifty-nine tests were conducted in light and 42 tests were conducted in the dark.

1979. Procedures for striped bass testing were essentially the same in 1979 as in 1978. However, four velocities (15.2, 30.5, 45.7, and 61.0 cm/sec) and four screen mesh sizes (1.0, 4.0, 5.0, and 9.5 mm) were investigated in the larval diversion model. Velocity of the water in the collection area ranged from 15.2 to 61.0 cm/sec, depending on the testing regime for that day. Control larvae were placed in the collection area, removed and held for 96 hours to determine latent mortality. In addition, a second control consisting of 25 larvae was utilized to separate out mortality arising from handling. Larvae for this control were removed from the stock tanks and placed directly into holding beakers for 96 hours.

At the start of each test, 50 larvae were introduced into the flume upstream of the angled screen. All tests were conducted under darkened conditions to facilitate testing since larvae moved more rapidly downstream under darkened conditions. Water temperature was recorded for each test, along with the start/stop times.

Larvae which had been entrained were collected on the containment screen. Larvae which had passed through the bypass were then removed to a holding beaker. A maximum of 25 live bypassed larvae were held for determination of latent mortality during the early stages of testing because the number of bypassed organisms was generally low. However, as the larvae grew and diversion efficiencies increased, all live bypassed larvae were held for 96 hours. In this case, the larvae were subdivided into smaller lots (generally less than 15 per beaker) to avoid overcrowding.

Observations of larvae which had been impinged on the angled screen or which were swimming in the flume were made during and at the conclusion of each test. These larvae, as well as entrained larvae, were removed from the flume at the end of each test but were not held for latent mortality since they were not diverted by the angled screens. As in the case of the impingement study, when a consistently large number of larvae were swimming in the flume at the end of a test at a given velocity, this velocity was removed from the testing matrix.

Mortality of bypassed larvae was recorded at 24, 48, 72, and 96 hours. At the end of the 96-hour holding period, the number of live larvae was recorded. Cannibalism among the larvae was observed but was not a major problem. However, as the larvae grew larger, they frequently jumped out of the holding beakers. Missing larvae were included in the overall test mortality figures in the interest of conservatism.

1980. In 1980, attempts were made to follow the same procedures in testing winter flounder, alewife, and yellow perch as had been employed with striped bass in 1978. However, as discussed later, these three species were difficult to test, particularly in their early life stages, due to their small size and transparent nature. Therefore, some changes in procedures were implemented in an attempt to gather as much data as possible. Since procedures varied by species, they are discussed further in the results section for each species.

Pump Studies

To determine the effects of passage through a jet pump on striped bass, winter flounder, alewife and yellow perch larvae, studies were conducted from June 1979 to June 1980. Mortality associated with pump passage was evaluated to determine the effectiveness of the pumping system in transporting larval fish with low mortality. In addition, in 1980, a hidrostal pump (screw-impeller) was tested to determine the survival potential of alewife and yellow perch larvae only after passage through this impeller-type pump. Descriptions of these pumps and the methods used to evaluate them are given individually below.

Jet Pump. A peripheral jet pump (Figure 7) was operated to evaluate its effectiveness in transporting larvae with low mortality. The suction tube of the pump was 7.12 cm pipe. A high velocity jet was formed at a nozzle around the end of this suction tube inside the pump. An 8.9 cm pipe formed the mixing tube for the jet flow and suction flow.

Following the mixing tube, the discharge pipe was expanded in a conical diffuser to a 25.4 cm diameter before entering a 30.5 cm deep collection area. Flow was introduced off-center in the circular collection area to produce circulation and was discharged through a semi-circular, 250 micron mesh retention screen over a gate controlling the water level.

The intake flow was controlled by a valve in a 15.2 cm pipeline supplying a tank. A 7.6 cm suction pipe supplied flow to the jet pump from this tank. A 3.2 cm clear flexible hose connected the tank to a larvae introduction box.

In the 1980 study, the introduction tank was replaced by a plexiglass section which connected the 15.2 cm supply pipe to the 7.6 cm suction pipe. A 1.9 cm tube entered the plexiglass section and ended at the center of the suction pipe. The test larvae were placed in a chamber which could be drained through this tube to introduce them into the jet pump.

The nozzle velocity was established at each test condition based on a measurement of nozzle flowrate and calculated nozzle area.

Hidrostal Pump. The use of a centrifugal pump has two main advantages over the jet pump. A centrifugal pump operates more efficiently (hydraulically) and is capable of pumping across greater water level differences. The disadvantage is that the rotating impeller might damage organisms while they are being pumped.

A hidrostal pump was chosen for study since its screw-type impeller has been designed to pump flows containing solid objects (including fish) without damage. The F4F pump utilized included a shroud on the screw section of the impeller to minimize abrasion of the larvae against the sides of the pump. The pump

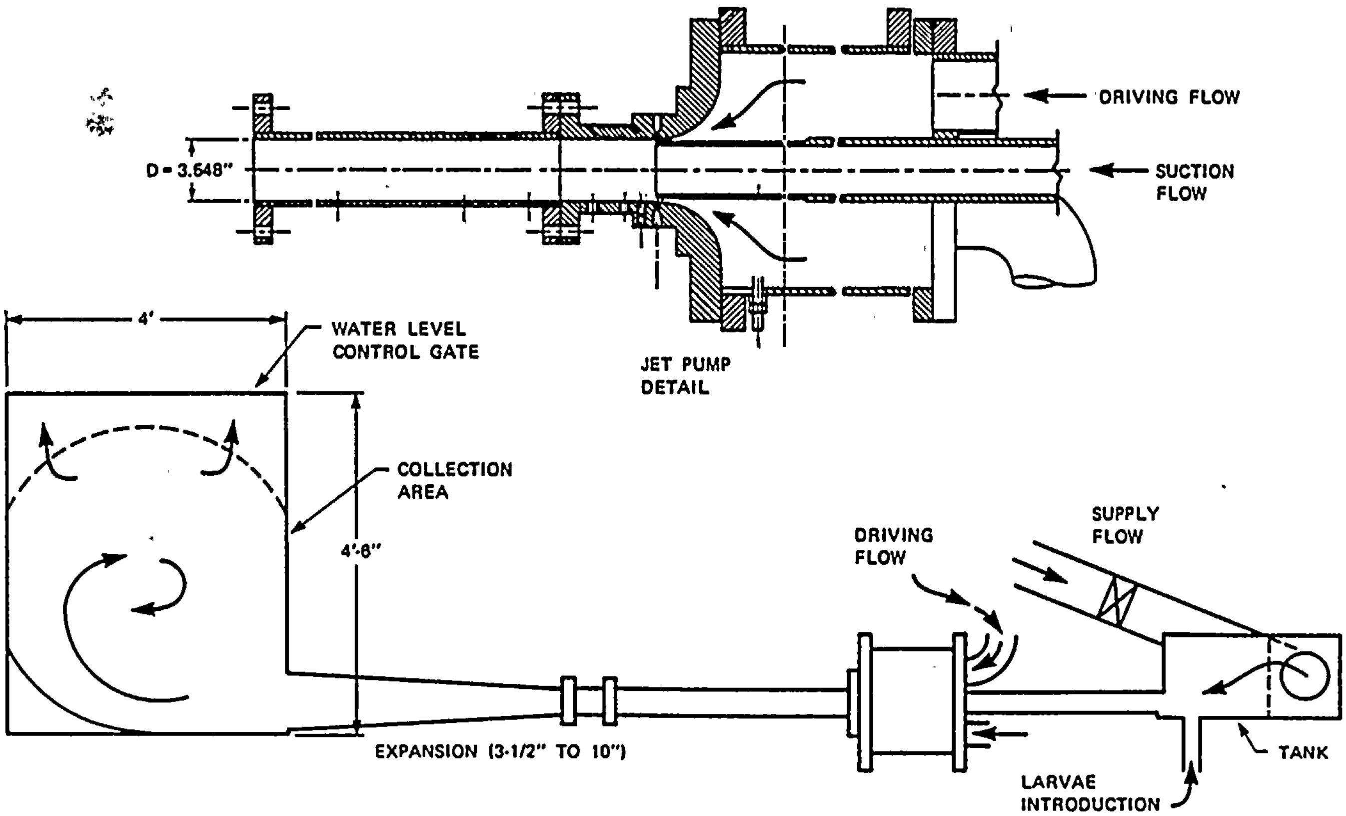


Figure 7. Jet pump test facility

was installed in a line parallel to the jet pump (Figure 8). The 10.2 cm discharge was vertical and went through an expansion to 25.4 cm diameter pipe. A short channel on top of the expansion carried the discharge to the jet pump collection area.

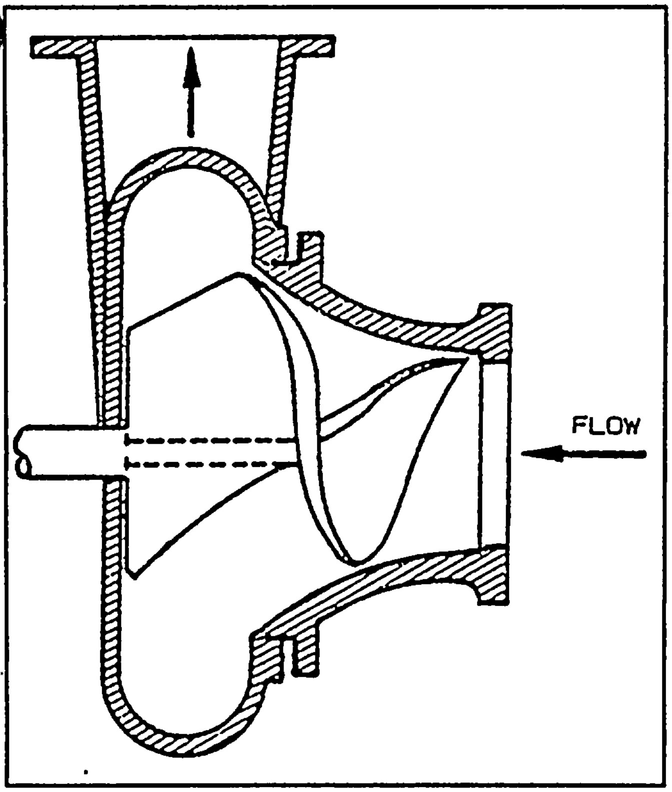


Figure 8. Screw-centrifugal pump source: hidrostal

Flow to the pump was measured by an orifice meter and was controlled by a valve in the 15.2 cm suction line. A plexiglass section of pipe mounted to the pump intake incorporated a fish introduction system similar to the one used in the jet pump tests. Fish were introduced through a 6.9 cm pipe at the center of the suction pipe 35.6 cm upstream of the pump.

Essentially the same procedures were used to test the jet and hidrostal pumps. Prior to the start of each test series, 25 control larvae were placed in the collection area of the flume with one of the pumps operating. These larvae were then removed from the collection area and were placed in holding beakers for 96 hours. In addition, a separate control was also established which consisted of larvae which were removed from the stock tanks and transferred directly to holding beakers and held for 96 hours.

At the start of each test, 25 larvae were placed into an introduction box. Upon release, the larvae were drawn into and through the pump, to be discharged into the collection area. The larvae were then removed from the collection area and placed in a holding beaker for 96 hours.

Initial mortality was recorded approximately one hour after the conclusion of each test. Thereafter, mortality was recorded at 24, 48, 72, and 96 hours for both test and control larvae with the exception of alewife and yellow perch prolarvae, which were held for only 48 hours. At the conclusion of 96 (or 48) hours, the number of live larvae in each beaker was recorded and the percent mortality was calculated.

RESULTS

The results of each study are presented individually below. In most cases, means and standard deviations (predicted from the ANOVA and ANCOVA models utilized in the data analysis) are presented in the data tables. Occasionally, 95 percent confidence intervals are presented for analyses that required transformations of that data. This was necessary since standard deviations estimated in a transformed scale are not meaningful in the original scale. Also, in some cases, test and control mortalities were both high and quite variable. In these instances, estimates of variability would be of little use, and they are not, therefore, presented.

Over the course of the entire study program, a total of over 3,000 tests were conducted (all models) utilizing over 75,000 fish larvae of all species. The number of tests conducted under each test condition in each model is presented in each data table.

IMPINGEMENT SURVIVAL STUDY

The results of impingement survival studies with striped bass, winter flounder, alewife, yellow perch, walleye, channel catfish, and bluegill are given in Tables 1 through 7. Each species is discussed individually below.

Striped Bass. The results of impingement survival studies with striped bass pro- and postlarvae are summarized in Table 1. The 5.4 to 6.4 mm prolarvae experienced relatively high mortality even under mild conditions of low velocity and short impingement duration. However, the high control mortality (56.5 percent) observed indicates that this life stage did not respond well to the handling procedures required in this study. Therefore, it is reasonable to assume that correspondingly high test mortalities were also partly a result of handling rather than impingement stress.

The results of testing with 6.5 to 17.1 mm postlarvae showed relatively high survival values under many conditions. The mortality values given apply to the mean larval length; the analysis of covariance showed that percent mortality decreased as larval length increased.

Winter Flounder. The results of winter flounder testing are given in Table 2. An analysis of variance indicated that impingement duration was not a

Table 1. Mean percent mortality (and standard deviation or 95-percent confidence intervals) striped bass impingement survival study.

Velocity (cm/sec)	Impingement Duration			
	2 Min	4 Min	8 Min	16 Min
a. 5.4–6.4 mm prolarvae (mean and standard deviation)				
15.2	74.2 ± 11.0 (4)	51.2 ± 24.2 (4)	91.8 ± 9.0 (4)	84.6 ± 18. (4)
30.5	63.4 ± 4.9 (3)	62.9 ± 6.9 (3)	90.7 ± 8.3 (3)	96.0 ± 6. (3)
45.7	70.7 ± 20.5 (3)	92.0 ± 8.0 (3)	98.7 ± 2.3 (3)	100.0 ± 0.0 (3)
61.0	97.3 ± 4.6 (3)	100.0 ± 0.0 (3)	100.0 ± 0.0 (3)	100.0 ± 0.0 (3)
b. 6.5–17.1 mm postlarvae (mean and 95-percent confidence interval)				
15.2	2.1— 3.8— 6.6 (26)	3.1— 5.5— 9.1 (26)	4.8— 8.2—13.5 (25)	37.3—43.9— 50.5 (2)
30.5	3.1— 5.3— 9.1 (28)	4.1— 6.8—11.0 (28)	11.4—17.5—26.6 (31)	51.2—58.9— 66.6 (3)
45.7	4.0— 6.4—10.0 (32)	5.8— 9.1—14.1 (32)	16.5—273—44.7 (23)	87.7—97.6—100.0 (5)
61.0	2.1— 4.2— 7.8 (20)	3.1— 6.0—10.8 (20)	22.6—475—98.5 (12)	—
91.4	10.9—18.4—26.0 (2)	34.2—49.1—64.0 (20)	—	—

Control Mortality (mean and standard deviation):
a. prolarvae = 56.5 ± 21.4 percent (8)
b postlarvae = 8.1 ± 17.1 percent (37)
Note: Number of tests given in parentheses

Table 2. Mean percent mortality (and standard deviation or 95-percent confidence intervals) winter flounder impingement survival study.

Velocity (cm/sec)	Impingement Duration		
	2 Min	8 Min	16 Min
a. 4.1 mm prolarvae (mean and 95-percent confidence intervals)			
15.2	—	3.6— 7.3—13.7 (8)	—
30.5	—	5.6—10.7—19.8 (8)	—
45.7	—	8.8—16.5—30.2 (8)	—
61.0	—	19.5—35.6—64.1 (8)	—
b. 4.4 mm early postlarvae (mean and standard deviation)			
15.2	64.9 ± 28.4 (8)	72.0 ± 24.0 (8)	66.8 ± 18.4 (8)
30.5	93.1 ± 13.1 (6)	100.0 ± 0.0 (6)	100.0 ± 0.0 (4)
45.7	93.1 ± 13.9 (4)	97.7 ± 2.7 (4)	—
61.0	100.0 ± 0.0 (4)	100.0 ± 0.0 (4)	—
c. 6.1 mm later postlarvae (mean and standard deviation)			
15.2	54.0 ± 19.8 (2)	62.0 ± 31.1 (2)	28.0 ± 33.9 (2)
30.5	22.0 ± 19.8 (2)	36.0 ± 28.3 (2)	—
45.7	34.0 ± 14.1 (2)	31.4 ± 4.8 (2)	—
61.0	16.4 ± 0.5 (2)	59.1 ± 6.9 (2)	—

Control Mortality (mean and standard deviation):
a. prolarvae = 4.1 ± 0.14 percent (2)
b early postlarvae = 42.5 ± 33 8 percent (3)
c late prolarvae = 8.3 percent (1)
Note: Number of tests given in parenthesis

Table 3. Mean percent mortality and standard deviation alewife impingement survival study.

Velocity (cm/sec)	Impingement Duration 2 Min	8 Min
a. 5.2–5.5 mm prolarvae		
15.2	5.1 ± 3.8 (4)	4.1 ± 4.1 (4)
30.5	11.8 ± 14.4 (4)	18.9 ± 14.1 (4)
45.7	10.5 ± 10.5 (4)	44.1 ± 7.4 (4)
61.0	28.2 ± 6.9 (4)	69.7 ± 6.6 (4)
b. 6.6–14.7 mm postlarvae		
15.2	76.3 ± 25.8 (16)	82.7 ± 24.1 (16)
30.5	84.0 ± 20.2 (16)	92.8 ± 12.3 (16)
45.7	92.5 ± 8.6 (16)	96.7 ± 5.3 (16)
61.0	90.5 ± 12.1 (14)	98.6 ± 4.3 (14)

Control Mortality (mean and standard deviation):
a. prolarvae = 0 percent (2)
b. postlarvae = 43.3 ± 36.2 percent (8)
Note: Number of tests given in parenthesis

Table 4. Mean percent mortality and standard deviation yellow perch impingement survival study.

Velocity (cm/sec)	Impingement Duration 2 Min	8 Min
a. 5.8–6.0 mm prolarvae		
15.2	5.0 ± 7.6 (4)	6.8 ± 5.9 (4)
30.5	5.9 ± 7.4 (4)	5.2 ± 4.0 (4)
45.7	12.1 ± 12.3 (4)	32.3 ± 6.1 (4)
61.0	9.1 ± 7.5 (4)	31.5 ± 12.6 (4)
b. 6.3–6.5 mm postlarvae		
15.2	97.1 ± 5.8 (4)	95.0 ± 5.0 (4)
30.5	92.0 ± 8.6 (4)	93.2 ± 8.0 (4)
45.7	88.7 ± 15.0 (4)	99.0 ± 2.0 (4)
61.0	91.1 ± 10.6 (4)	94.9 ± 7.9 (4)
c. 7.3–14.3 mm postlarvae		
15.2	31.9 ± 25.6 (10)	40.0 ± 26.2 (10)
30.5	47.7 ± 31.6 (10)	71.4 ± 22.4 (10)
45.7	55.9 ± 25.8 (10)	80.0 ± 15.5 (10)
61.0	67.0 ± 26.9 (10)	83.0 ± 20.3 (10)

Control Mortality (mean and standard deviation):
a. prolarvae = 4.1 ± 0.14 percent (2)
b. postlarvae = 85.2 ± 9.7 (2)
c. postlarvae = 32.8 ± 31.2 (5)
Note: Number of tests given in parentheses

Table 5. Mean percent mortality (24-hour) walleye impingement survival study.

Velocity (cm/sec)	Impingement Duration 2 Min	4 Min	8 Min	16 Min
15.2	31.4 (24)	34.7 (24)	31.9 (24)	39.5 (24)
30.5	42.8 (25)	55.0 (25)	58.4 (17)	69.9 (17)
45.7	38.8 (22)	46.3 (22)	60.6 (9)	80.6 (7)
61.0	46.1 (17)	45.0 (17)	79.6 (6)	100.0 (3)
91.4	67.4 (9)	92.5 (9)	94.7 (4)	100.0 (3)

Mean Control Mortality = 26.8 percent (22)
Note: Number of tests given in parentheses

Table 6. Mean percent mortality channel catfish impingement survival study.

Velocity (cm/sec)	Impingement Duration 2 Min	4 Min	8 Min	16 Min
a. 11.2–15.5 mm larvae				
15.2	1.4	4.8	3.0	3.1
30.5	2.2	5.2	3.1	9.3
45.7	4.5	9.2	5.4	13.8
61.0	3.2	5.2	3.6	15.8
91.4	4.3	9.2	13.9	50.8

(Note: Standard deviation around all values = 3.8 percent were conducted at each velocity/duration combination.

Velocity (cm/sec)	2 Min	4 Min	8 Min	16 Min
b. 15.5–25.7 mm larvae				
61.0	—	6.8	—	19.6
91.4	—	5.4	—	36.1

(Note: Standard deviation around all values = 3.0 percent. Tests were conducted at each velocity/duration combination.
Mean Control Mortality and Standard Deviation:
All tests = 3.9 *F* 6.5 percent (40)

Table 7. Mean percent mortality and 95-percent confidence intervals bluegill impingement survival study.

Velocity (cm/sec)	Impingement Duration 2 Min	4 Min	8 Min	16 Min	Number of Tests
15.2	1.6—3.4—5.2	1.6—3.4— 5.2	1.6— 3.4— 5.2	1.6— 3.4— 5.2	28
30.5	0.3—2.3—6.1	0.1—1.8— 5.3	0.1— 1.5— 4.8	1.0— 4.0— 8.7	64
45.7	0.1—1.4—4.6	0.4—2.5— 6.5	8.3—14.3—21.5	33.6—42.8—52.3	66
61.0	0.4—2.5—6.3	0.3—2.3— 6.0	18.4—26.3—35.0	56.2—65.5—74.2	68
91.4	0.8—2.1—5.5	4.4—9.4—15.8	52.0—61.1—69.8	93.3—97.3—99.6	68

Mean Control Mortality and Standard Deviation = 2.7 ± 4.3 percent (30)
Note: Total number of tests at each velocity were equally distributed over the four impingement durations.

significant variable in impingement mortality among prolarvae; therefore, mean mortality values over all durations are given for each velocity, which was a significant variable.

Higher mortality among 4.4 mm postlarvae was expected since mortality among winter flounder naturally increases during transition from pro- to postlarvae, as reflected in the higher control mortality. The fact that mortality among later (6.1 mm) postlarvae was substantially reduced from the earlier values indicates that highest mortalities among winter flounder can be expected during and shortly after transition stages. However, relatively high mortalities were still observed among the later postlarvae (relative to the control group), indicating that flounder larvae at this length are somewhat sensitive to impingement stress.

Alewife. A total of 32 tests were conducted with alewife prolarvae on two separate days; mean larvae lengths were 5.2 and 55 mm, respectively. As shown in Table 3, mortality increased with velocity and was generally higher at the longer impingement duration. The lack of mortality among control larvae indicates that observed test mortalities resulted from impingement stress.

Mortality among alewife postlarvae was substantially higher than with prolarvae (Table 3). A total of 124 tests were conducted as the larvae grew from 6.6 to 14.7 mm. Test mortality was generally high, while control mortality was highly variable, ranging from four to 100 percent. Control mortality decreased as the larvae grew, indicating that impingement stress became more important in explaining mortality as the larvae developed, as compared to natural and unexplained mortality which occurred early in the postlarval stage.

Yellow Perch. Results of 144 tests (Table 4) with pro- and postlarval yellow perch were similar to those obtained with alewife and flounder. Prolarval (5.8-6.0 mm) mortality was low, while postlarvae showed high

mortality during transition from the pro- to the postlarval stage (6.3 to 6.5 mm) with a trend toward decreasing mortality thereafter (7.3 to 14.3 mm). Therefore, it appears that early postlarval mortality was largely a function of natural causes (control mortality of 6.3 to 6.5 mm larvae was 85.2 percent); among later postlarvae, mortality appears to be more attributable to impingement stress.

Walleye. A total of 308 tests were conducted with larvae ranging in length from 8.4 to 12.0 mm. Test and control mortalities during the test period were very high and increased as the larvae grew. This mortality had been expected since the problems of rearing walleye larvae in the laboratory have been well-documented. In an effort to draw some conclusions from the available data, the results were analyzed differently from the other test species.

Analyses of control group mortalities showed that mortality increased with age and increased with holding time (24, 48, 72 and 96 hours) at a given larval length. These relationships are shown on Figure 9. It was clear from these results that use of 96-hour mortality would not yield meaningful interpretations of the data. Therefore, subsequent analyses concentrated on 24-hour mortalities.

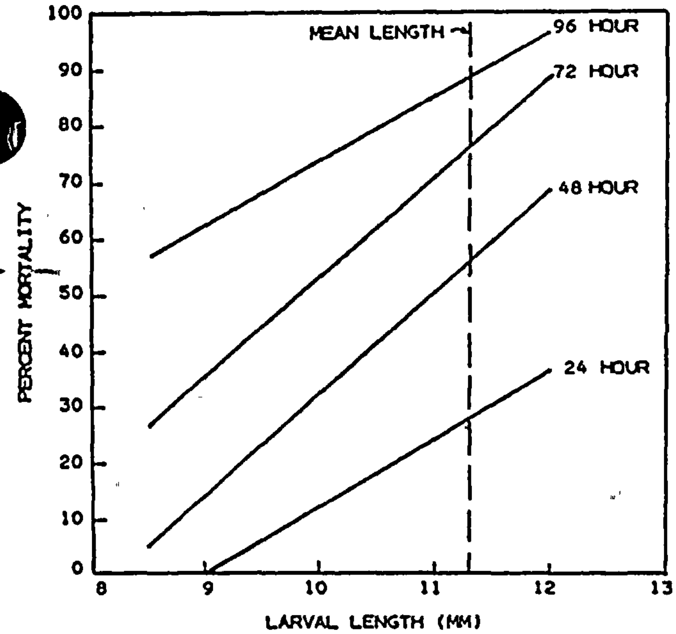


Figure 9. Walleye control mortality

Results of walleye testing, given as 24-hour mortalities, are presented in Table 5. It can be seen that under less stressful conditions of velocity and impingement duration, mean test mortalities did not greatly exceed mean control mortality.

Since mortality among walleye test and control larvae increased with age, a trend which is opposite that which would be expected, it is believed that the observed relationship between larval length and mortality is more a function of deterioration in condition over time than some length- or age-specific factor which reduces the survival potential of walleye as they grow.

Channel Catfish. A total of 280 tests were conducted with channel catfish ranging in length from 11.2 to 25.7 mm. As shown in Table 6, mortality among test and control larvae was low under most conditions, even those of high velocity and extended impingement duration. It is clear that this species is very hardy and would be expected to survive impingement under most power plant conditions.

Bluegill. A total of 294 tests were conducted with bluegill larvae ranging in length from 15.3 to 21.0 mm. As with channel catfish, mortality was low under most conditions, as shown in Table 7. Results of analyses showed that, except for larvae impinged for eight and 16 minutes at velocities of 45.7, 61.0 and 91.4, mortalities were not significantly different under all other velocity/duration combinations. Thus, it is clear that the bluegill is a hardy species and should survive impingement under power plant conditions.

SCREEN RETENTION STUDY

Striped bass, winter flounder, alewife, and yellow perch larvae were tested in the screen retention model under various combinations contained in the following velocity/mesh size matrix:

Velocity (cm/sec)	Mesh Size (mm) 0.355	0.5	1.0	1.5	2.0
15.2	X	X	X	X	X
30.5	X	X	X	X	X
45.7	X	X	X	X	X
61.0	X	X	X	X	X

The results of testing with each species are given below. While results are presented for various larval lengths, it should be recognized that body depth is an important factor in retention; variations in retention values between species at specific lengths may be explained by differences in body depth.

Striped Bass. During the course of the study, the larvae grew from 5.4 to 21.5 mm in length. As expected, retention on each mesh size tested increased with larval length. Within the range of independent variables examined, approach velocity did not influence the percentage of larvae retained.

The results of striped bass testing are shown graphically on Figure 10 as the relationship between retention and larval length for each mesh size. The smallest larvae tested (5.4 mm) were completely retained on the 0.5 mm mesh; thus, the relationship between length and retention is seen as a horizontal

line. The following table summarizes the relationship between larval length and percent retained (predicted) for each mesh size: .

Mesh Size (mm)	Larval Length Tested (mm)	Number of Tests	Larval Length and Predicted Percent Retained	
			50 percent	100 Percent
0.5	5.4 - 6.9	12	—	5.4 mm
1.0	5.4 - 9.9	39	9.5 mm	10.3 mm
1.5	5.4 - 17.4	57	14.1 mm	15.4 mm
2.0	10.8 - 21.5	30	17.5 mm	18.7 mm

Note: Predictions based on analysis of covariance model.

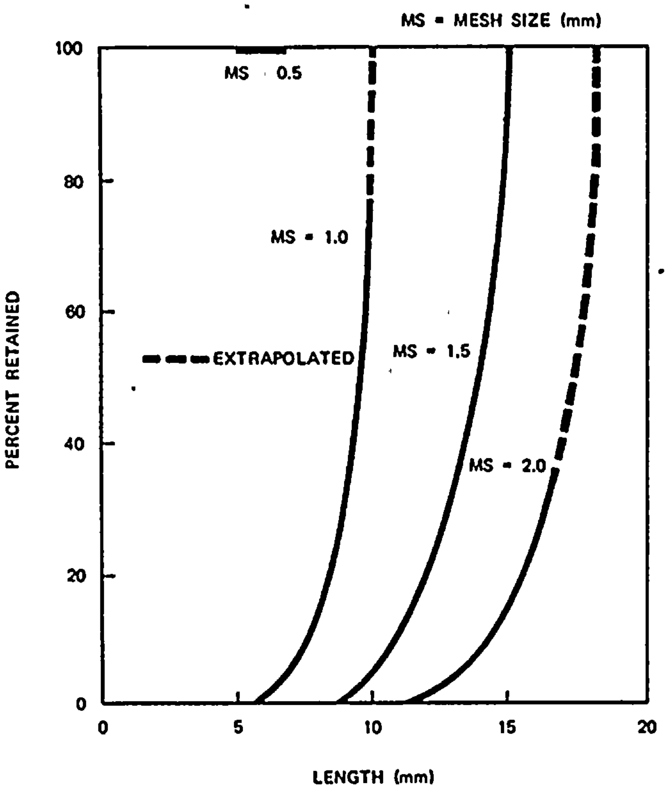


Figure 10. Striped bass retention versus length at various mesh sizes

Winter Flounder. This species was tested during the prolarval and postlarval life stages. Prolarvae ranged from 3.6 to 4.4 mm with a mean length of 4.1 mm; therefore, testing was concentrated on the smaller mesh sizes. Nearly 100 percent retention was obtained with the 0.355 mm mesh (four tests) at a velocity of 15.2 cm/sec. With the 0.5 mm mesh, there was no significant difference between retention values at 15.2 and 30.5 cm/sec; the mean retention was 73.3 percent (16 tests) with a 95 percent confidence interval of 67.4 to 79.1 percent. The 1.0 mm mesh was tested at a velocity of 15.2 cm/sec only; mean retention was 2.3 percent (eight tests) with a 95 percent confidence interval of zero to 3.3 percent.

Winter flounder early postlarvae were tested on one day when they had a mean length of 4.4. The 0.355 mm mesh was not tested since retention of smaller prolarvae had shown nearly 100 percent retention. With the 0.5 mm mesh, mean retention and standard deviations were 63 ± 10 percent and 81 ± 5 percent at velocities of 15.2 and 30.5 cm/sec, respectively. It might be expected that retention would decrease as velocity increases. However, at lower velocities, larvae tended to orient into the current aligning perpendicular to the mesh. In this orientation, they were more likely to pass through the mesh opening. At higher velocities, the larvae were disoriented and contacted the mesh in a random fashion. Naturally, an orientation parallel to the mesh would result in impingement across a number of mesh strands, thus causing the larvae to be held in place by the flow. At a velocity of 15.2 cm/sec, the 1.0 mm mesh retained only 12 percent (standard deviation of 9.8 percent) of the postlarvae.

Alewife. Alewife were also tested as pro- and postlarvae. Prolarvae ranged in length from 5.0 to 5.4 mm, with a mean length of 5.2 mm. Due to their small body depth and size, testing was concentrated on the 0.355 and 0.5 mm mesh. With the 0.355 mm mesh, mean retentions and standard deviations were 64 ± 8.6 percent and 97 ± 3.8 percent at approach velocities of 15.2 and 45.7 cm/sec, respectively. Greater retention at the higher velocity was again a function of larval orientation in the flow. With the 0.5 mm mesh, mean retention was only 2 percent (standard deviation of 2.3 percent).

Alewife postlarvae were tested at two mean lengths of 6.6 and 9.5 mm. The 6.6 mm larvae were tested on two different dates, seven days apart, with slightly different results. The results of all prolarval testing are given below:

Mean Length (mm)	Mesh Size and Velocity (cm/sec)			
	0.355 mm		0.5 mm	
	15.2	45.7	15.2	45.7
6.6	87.0 ± 14.4	96.0 ± 3.3	10.0 ± 7.0	—
6.6	100.0 ± 0.0	100.0 ± 0.0	20.0 ± 8.2	77.5 ± 32.0
9.5	—	—	89.2 ± 15.7	92.5 ± 5.0

Mean Length (mm)	Mesh Size and Velocity (cm/sec)	
	.0 mm	
	15.2	45.7
6.6	—	—
6.6	—	—
9.5	0 ± 0	30.0 ± 8.2

Note: 4 tests were conducted at each length/velocity/mesh size combination.

Yellow Perch. This species was also tested as pro-postlarvae. Prolarvae ranged in length from 5.4 to 5.9 mm, with a mean length of 5.75 mm on the day they were tested. Test results are given below:

Velocity (cm/sec)	Mesh Size (mm)		
	0.335	0.5	1.0
15.2	75.0 ± 9.5	48.0 ± 14.6	1.0 ± 2.0
45.7	97.0 ± 3.8	83.0 ± 11.9	—

Note: 4 tests were conducted at each velocity/mesh size condition.

Postlarvae were tested on four separate days at mean lengths of 6.3, 7.3, 8.1 and 9.3 mm. Test results are given in Table 8.

AIR EXPOSURE STUDY

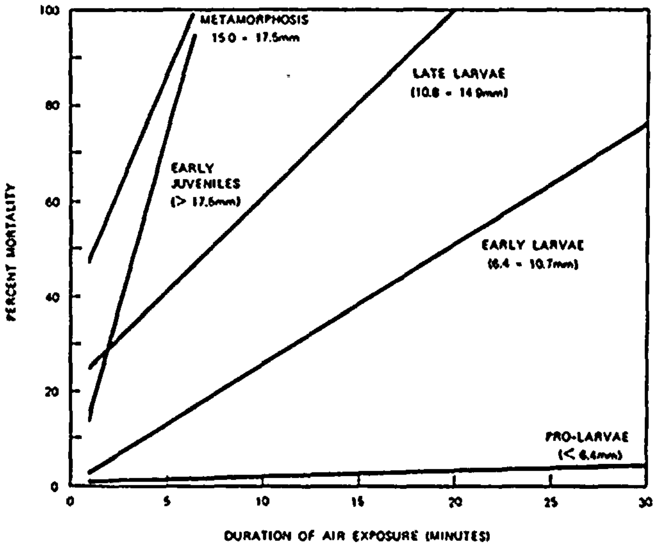
Results of the air exposure study indicate that the effects of exposure are species- and life stage-dependent. The results of striped bass testing are presented graphically on Figure 11. It is evident that prolarvae can survive air exposure for long durations with little or no ill effects. Among larvae tested after

Table 8. Postlarvae — percent retained and standard deviation yellow perch screen retention study.

Mean Length (mm)	Mesh Size and Velocity (cm/sec)			
	0.355 mm		0.5 mm	
	15.2	45.7	15.2	45.7
6.3	92.0 ± 11.3	98.0 ± 2.3	91.0 ± 10.5	97.0 ± 3.8
7.3	—	—	100.0 ± 0.0	100.0 ± 0.0
8.1	—	—	100.0 ± 0.0	100.0 ± 0.0
9.3	—	—	—	—

Mean Length (mm)	Mesh Size and Velocity (cm/sec)			
	1.0 mm		1.5 mm	
	15.2	45.7	15.2	45.7
6.3	0.0 ± 0.0	—	—	—
7.3	6.7 ± 5.8	36.7 ± 11.5	—	—
8.1	15.0 ± 17.3	37.5 ± 12.6	—	—
9.3	94.5 ± 6.4	100.0 ± 0.0	35.0 ± 17.3	37.5 ± 12.6

Note: Each mean percent retained value is based on four tests



CONTROL MORTALITY (MEAN AND STANDARD DEVIATION):

PRO-LARVAE 0±0(2)
EARLY LARVAE 16±24.3(3)
LATE LARVAE 10±8.5(2)
METAMORPHOSIS 49.3±42.8(3)
EARLY JUVENILES 14.7±10(3)

NOTE: NUMBER OF TESTS GIVEN IN PARENTHESES

Figure 11. Striped bass test mortality (97-hour) versus air exposure duration partitioned by life stage

yolk sac absorption, mortality generally increased with age, with the highest mortality occurring during metamorphosis to the juvenile stage.

Winter flounder prolarvae and postlarvae were each tested on two separate days. Results are given below:

in all studies and generally resulted in higher mortalities at that time.

Mortality among alewife prolarvae (mean length of 5.2 mm) was nearly zero at all three durations of air exposure (nine tests). Mortality among postlarvae, ranging in mean length from 6.6 to 12.4 mm, was generally high in both test and control groups (27 tests). Since the mean control mortality often exceeded test mortalitie~ these data do not clearly demonstrate whether alewife postlarvae can withstand air exposure. Nearly identical results were obtained with yellow perch pro- and postlarvae. In nine tests with prolarvae, mean mortality was less than one percent over all three exposure times. Postlarvae experienced greater than 76 percent mortality (generally over 90 percent) under all conditions in both test and control groups. Again, conclusions cannot be drawn from these data.

SPRAYWASH STUDY

Striped bass postlarvae and juveniles (19 to 35.5 mm in length) were tested in both the front- and back-wash test apparatus. Twenty-six tests were conducted with each spraywash type. Results of an analysis of covariance indicate that the two spray types were not significantly different and that mortality did not change significantly with larval length. The overall mean mortality for all tests was 2.3 percent with a 95 percent confidence interval of 1.4 to 3.6 percent; mean control mortality was 2.1 percent.

Mean Length (mm)	Mean Percent Mortality by Duration			Control Mortality (percent)
	1 Min	3 Min	5 Min	
3.6	0.0 ± 0.0	8.0 ± 11.3	50.0 ± 53.2	4
4.1	1.0 ± 1.9	1.7 ± 2.0	1.8 ± 3.6	4
4.4	32.2 ± 12.4	63.9 ± 19.4	59.8 ± 25.7	0
6.1	0.0 ± 0.0	4.0	8.0	4

Note: Values based on four tests except for 6.1 mm larvae which were tested twice. Control mortality values based on one control group at each larval length.

The 50.0 percent mortality observed amont 3.6 mm prolarvae at five-minute exposure results from two 96 percent values obtained in two of four tests conducted. Mean mortality in the other two tests was only four percent. The reason for this discrepancy is unknown, but it appears that the higher mortality values are anomalous considering the low mortality (1.8 percent) obtained with prolarvae of slightly larger size at a five-minute exposure time. The higher mortalities among 4.4 mm early postlarvae were expected; a natural die-off that occurs during transition from the pro- to postlarval stage and continues fcr a short period thereafter was observed

As previously discussed, winter flounder, alewife, and yellow perch pro- and postlarvae were tested only with the back-wash system. In attempting to test winter flounder pro- and postlarvae (3.6 to 4.4 mm), alewife prolarvae (5.0 to 5.8 mm) and yellow perch prolarvae (5.9 to 6.1 mm), it was found that the majority of the larvae adhered to the mesh where it joined the lifting bucket and were not washed into the collection area. Therefore, survival data was not obtained.

Similar results were obtained with alewife (8.7 to 13.2 mm) and yellow perch (6.0 to 8.9 mm)

postlarvae. While more individuals were recovered from the collection area, generally more than 50 percent of those tested adhered to the mesh despite their size. Of those collected and held, mortality among both species was high. However, control mortality was also high, thus limiting the ability to draw conclusions from these data.

This study indicates that minor design details in a fine-mesh screen can greatly affect the capability of this type of collection system for protecting organisms. The problems encountered in this study must be resolved through design changes if a back-wash system is to be effective. Such changes should be relatively easy to implement. However, it was not within the scope of this study to conduct developmental research.

ANGLED SCREEN DIVERSION STUDY

As previously discussed, angled screen diversion testing procedures differed slightly from 1978 to 1980. Therefore, results of 1978 and 1979 striped bass tests and 1980 winter flounder, alewife and yellow perch tests are presented individually below.

1978. A total of 101 tests were conducted with striped bass larvae under both light and dark conditions. Since the 42 tests conducted under dark conditions more accurately represent conditions which would exist at a power plant, only these tests were subjected to analysis. Eleven tests were conducted with the 1.5 mm synthetic screen, 10 tests each with the 15 mm metallic and 2.5 mm synthetic screen, and 11 tests with the 2.5 mm metallic screen. The measure of success of the screens in diverting larvae without mortality was Total Efficiency (TE), which is a function of diversion efficiency adjusted for 96-hour mortality among successfully diverted larvae.

Results of testing under all conditions are presented graphically on Figures 12 and 13 for the 1.55 and 2.5 mm meshes, respectively. As can be seen, TE increased with increasing larval length, as expected. Results of ANCOVA indicated that mesh size and type significantly influenced TE, with the 1.5 mm mesh yielding greater efficiencies than the 2.5 mm mesh and the synthetic mesh yielding higher diversion efficiencies than the metallic mesh. The predicted TE lines shown on Figures 12 and 13 indicate a slightly higher efficiency at 30.5 cm/sec (1.0 fps) than at 15.2 cm/sec (0.5 fps). However, this is believed to result from the fact that the 30.5 cm/sec approach velocity was not tested until the larvae had reached a length of almost 15 mm.

As shown on Figure 12, results of testing with the 1.5 mm mesh were highly variable over the range of larval lengths tested. Therefore, the usefulness of the regression lines to predict TE is somewhat limited. However, the general trends given are believed to be fairly accurate, as supported by the 1979 data discussed below (refer to Figure 15).

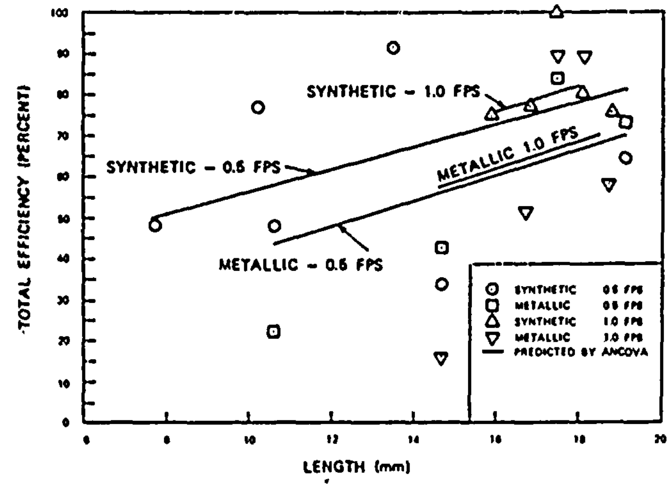


Figure 12. Total efficiency versus length for 1.5mm mesh 1978 striped bass diversion study

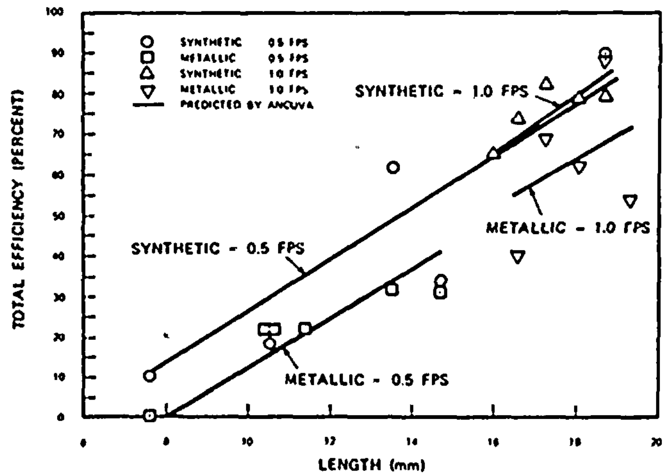


Figure 13. Total efficiency versus length for 2.5mm mesh 1978 striped bass diversion study

1979. Based on results of testing in 1978, only synthetic meshes were evaluated with striped bass in 1979, and larger mesh sizes were added to the study. A total of 203 tests were analyzed: 29 with a 1.0 mm mesh, 38 with a 4.0 mm mesh, 70 with a 5.0 mm mesh and 66 with a 9.5 mm mesh. Testing was conducted in a sequential manner beginning with the smallest mesh and lowest velocity. Once diversion was observed, the next largest mesh size and velocity were added to the testing regime. All tests were conducted under dark conditions. During the testing period, the striped bass grew from 9.9 to 41.1 mm in length.

Results of 1979 testing are presented on Figure 14 as a plot of TE versus larval length averaged over all velocities tested. The following table summarizes the larval lengths at which total efficiencies of 25, 50 and 100 percent are predicted to occur (based on the ANCOVA model):

Mesh Size (mm)	Range of Larval Lengths (mm) Tested	Predicted Total Efficiency 25%	50%	100%
1.0	9.9 - 18.0	—	8.2 mm	16.1 mm
4.0	10.4 - 24.7	13.6 mm	17.6 mm	25.5 mm
5.0	16.3 - 31.7	—	20.0 mm	32.1 mm
9.5	18.0 - 41.1	22.8 mm	28.8 mm	41.0 mm

Note: Some values exceed the lengths of larvae tested since they are predicted from the ANCOVA.

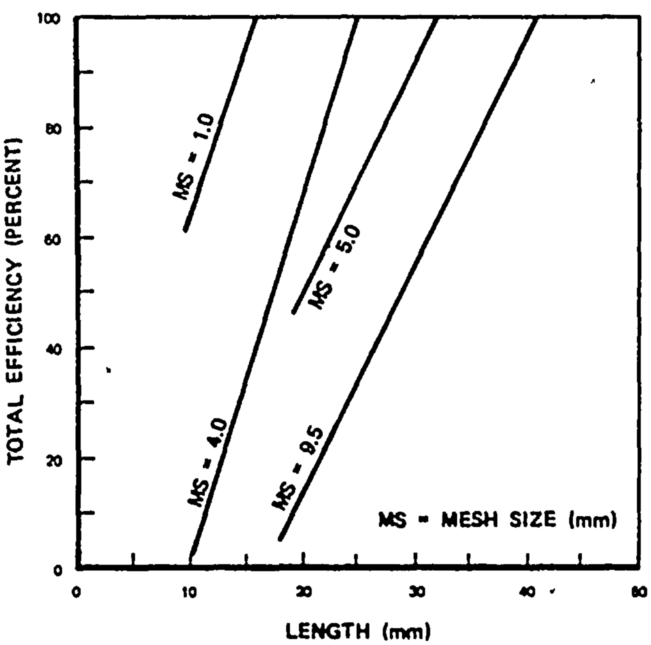


Figure 14. Total efficiency versus length averaged over all velocities 1979 striped bass diversion study.

In general, these results are similar to those obtained in 1978; TE increased with larval length (*i.e.*, as swimming ability increased). As expected, mesh size influenced TE in such a way that the larval length at which a specific efficiency value was achieved increased with each successive increase in mesh size.

A separate analysis was conducted to evaluate the effect of approach velocity on the TE obtained with each mesh size. Results are presented on Figure 15. Again, at a specific larval length, TE decreased with increasing mesh size; TE also decreased with increasing velocity at each mesh size.

1980. Angled screen diversion studies were conducted with winter flounder, alewife, and yellow perch larvae in 1980. Flounder were only available for testing over a 4.1 to 6.1 mm length range. In four tests, no diversion was noted.

Alewife prolarvae (mean length of 5.5 mm) and early postlarvae (mean length of 9.5 mm) also showed no ability to guide along the angled screen in single tests with the 1.0 mm screen at 15.2 cm/sec. Later postlarvae showed relatively high diversion efficiencies. In two tests with 11.2 mm larvae, diversion efficiencies were 84 and 77 percent; in three tests with 14.7 mm larvae, efficiencies of 84, 84 and 60 percent were obtained. However, in all five tests, 96-hour mortalities were high, and total efficiencies were, therefore, low (less than 27 percent). The majority of postlarvae tested were observed to impinge on the 1.0 mm mesh for varying periods of time prior to being diverted into the bypass; since control mortality was low, it would appear that stress from impingement contributed to the high mortalities which occurred.

As with the other species, smaller yellow perch larvae (mean lengths of 6.0 to 9.3 mm) showed no ability to guide along the 1.0 mm mesh at 15.2 cm/sec (six tests). In two tests with 14.3 mm perch, diversion efficiencies of 16 and 72 percent were obtained; respective 96-hour mortalities were 11.1 and one percent. Further testing was not possible since additional yellow perch larvae were not available.

PUMP STUDIES

As previously discussed, angled screen systems require pumps to return bypassed organisms to their natural environment. Accordingly, a jet pump and hidrostal pump were evaluated for ESEERCO to determine their ability to transport striped bass, winter flounder, alewife, and yellow perch with low resultant mortality. Results of testing with each pump and species is presented below.

Jet pump. A total of 126 tests were conducted with striped bass larvae ranging in length from 7.5 to 35.5 mm. Two nozzle velocities of 35 and 49 km/hr were evaluated; however, percent mortality did not differ significantly. Mean mortality for all tests was 4.7 percent with a 95-percent confidence interval of 3.7 to 6.1 percent. Control larvae experienced a mean mortality of 2.6 percent with a 95-percent confidence interval of 1.4 to 4.4 percent.

Winter flounder pro- and postlarvae (3.6 to 4.4 mm) were not successfully tested in the jet pump

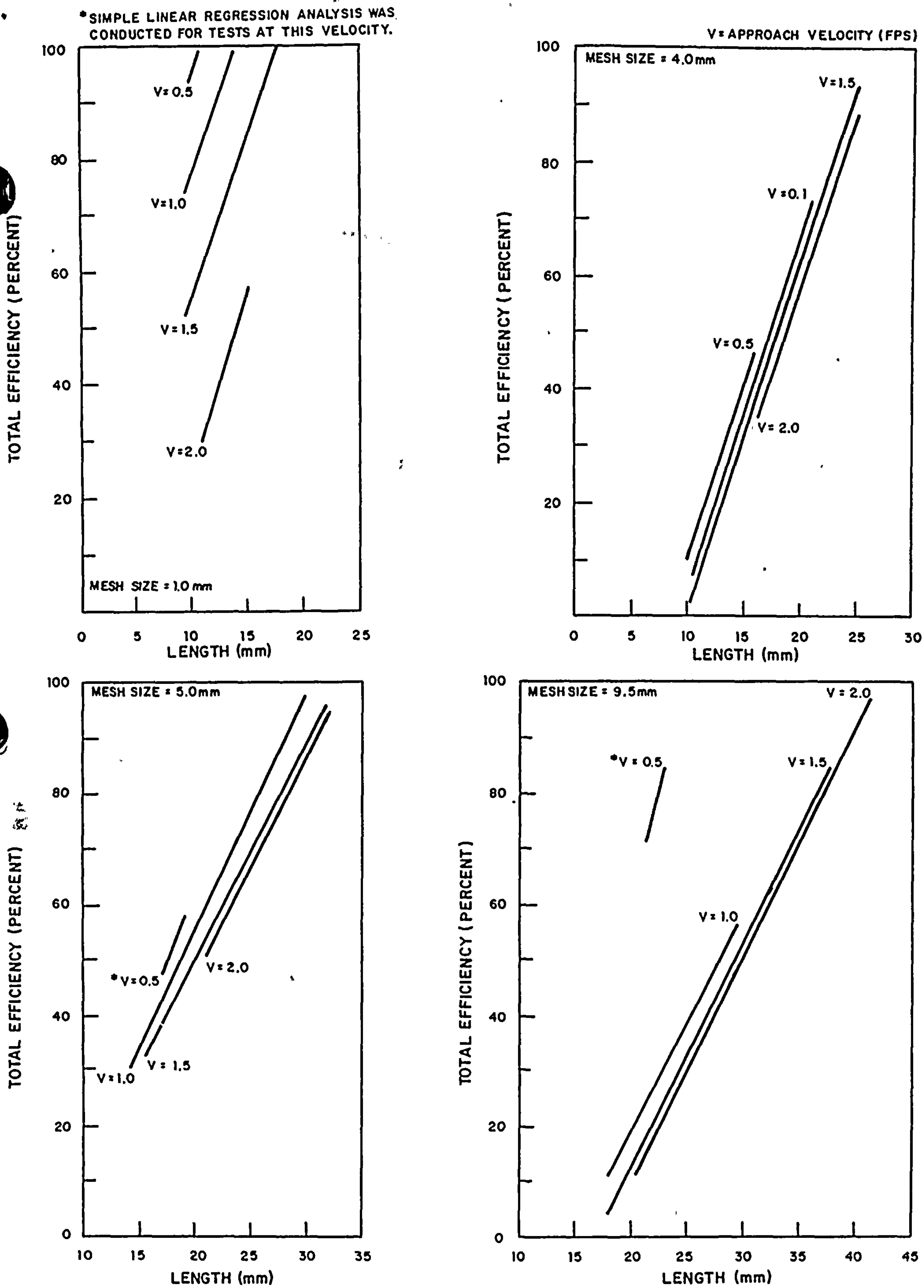


Figure 15. Efficiency versus length averaged velocities 1979 striped bass diversion study

since their small size and transparent nature made it impossible to recover them from the collection area. A small group of older larvae (6.1 mm) were tested later in the study. However, due to their limited swimming ability, most larvae impinged on the retention screen in the collection area. Therefore, while mean mortality (three tests) was 52 percent, it is not possible to separate pump mortality from impingement and collection mortality. Control mortality was 8.3 percent.

Alewife prolarvae (mean length of 6.0 mm) were difficult to test due to their small size and transparent nature which necessitated more extensive handling during collection than with larger larvae. Test mortality in two tests was 40 and 76 percent, while control mortality was 16 percent. Alewife postlarvae were tested at mean lengths of 9.6 and 12.4 mm. Mean mortality among the two test groups was 80 and 69.5 percent, respectively. Associated control mortalities were 8.3 and 32 percent.

Yellow perch prolarvae were also difficult to recover; however, one test with these 6 mm larvae was successfully completed. Test mortality was 32 percent; controls were not held. Postlarvae were tested at four different mean lengths. Results are given below:

Mean Length (mm)	Number of Tests	Mean Test Mortality (percent)	Control Mortality (percent)
6.5	3	91.2	65.2
7.3	2	44.8	17.4
8.1	4	86.5	79.2
19.4	2	10.0	0

Hidrostal Pump. The hidrostal pump was evaluated with alewife and yellow perch larvae only. Alewife prolarvae could not be successfully tested due to their small size. Postlarvae were tested at mean lengths of 9.6 mm (three tests) and 12.4 mm (three tests). Mean test and control mortality among the 9.6 mm group was 22.4 and 23.1 percent, respectively. Mean test and control mortality among the 12.4 mm group was 46.2 and 32 percent, respectively.

Yellow perch prolarvae (mean length of 6.1 mm) were successfully tested in the hidrostal pump. In three tests, mean mortality was 8.3 percent; no control larvae died. Yellow perch postlarvae were tested in four length groups, as presented below:

Mean Length (mm)	Number of Tests	Mean Test Mortality (percent)	Control Mortality (percent)
6.5	3	93.2	72.0
7.3	3	9.7	20.0
7.6	3	52.4	57.7
19.4	2	0	0

DISCUSSION

The purpose of the studies described in this paper was to evaluate the potential effectiveness of organism collection and diversion systems in protecting fish larvae at cooling water intakes. It is clear that each system, and its component parts (stresses), varies in potential effectiveness depending on the species and larval stage to be protected.

With respect to impingement and removal systems (fine-mesh traveling screens), the following general conclusions can be drawn:

- Striped bass prolarvae exhibited high impingement mortality under all conditions, while winter flounder, alewife, and yellow perch prolarvae exhibited low mortality; however, high control mortality among prolarval bass indicates that the mortality was not solely attributable to impingement.
- Impingement mortality was highest among winter flounder, alewife, and yellow perch postlarvae for a short period following absorption of the yolk sac; however, control mortality was also highest at this time.
- Impingement mortality estimates for walleye are difficult to interpret due to the high test and control mortalities which occurred; however, it does not appear that mortality among test organisms was solely a function of impingement.
- Channel catfish and bluegill are hardy species, as reflected by high survival even under relatively stringent impingement conditions.
- Screen retention is largely a function of mesh size relative to larval length and body depth; it would appear that for some species a mesh size of 0.5 mm or less may be required to effectively retain all larval stages. However, the laboratory studies did not account for the effects of water-borne debris which occurs *in situ* and aids in retaining organisms on a mesh.
- Air exposure may be a significant factor in mortality for certain species, particularly among postlarvae; it would appear prudent to limit exposure time in fine-mesh screen systems unless specific data is available which indicates that the species of concern at a site are resistant to air exposure stress.

- Spraywash studies demonstrate that minor details in the design of a fine-mesh screen can greatly affect overall system effectiveness.

With respect to larval diversion and pumping systems, the following conclusions can be drawn:

- Angled fine-mesh screens appear to have the potential for diverting older larvae to bypasses provided the proper mesh size and velocity are incorporated into the system design. Laboratory or field studies should be conducted with the species of concern at a particular site, since diversion capability is species-specific and may be influenced by site-specific physical and environmental parameters.
- Pumps appear to offer a potentially effective means for supplying the energy needed to return fish larvae to a release location following diversion; under the conditions tested, a screw-impeller (hidrostal), centrifugal pump appeared to induce less mortality among alewife and yellow perch larvae than a jet pump. However, the jet pump was highly effective in pumping striped bass larvae with low resultant mortality.