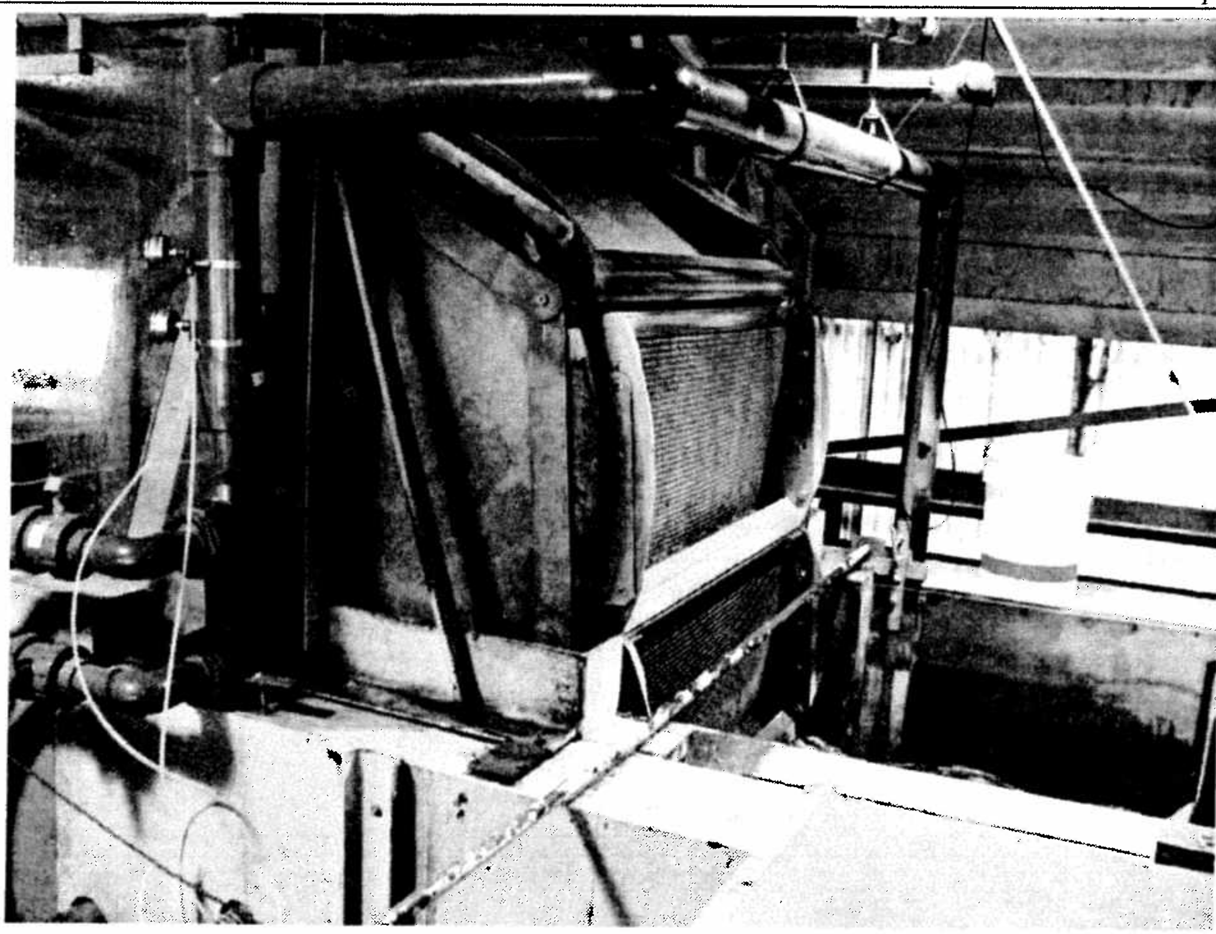
Laboratory Evaluation of Modified Ristroph Traveling Screens for Protecting Fish at Cooling Water Intakes

Technical Report



Laboratory Evaluation of Modified Ristroph Traveling Screens for Protecting Fish at Cooling Water Intakes

1013238

Final Report, June 2006

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REPORT SUMMARY

This report presents results of a laboratory study evaluating injury and survival of fish exposed to modified traveling water screens specifically designed to protect juvenile and adult fish. Information in this report increases the performance database for this technology. The data presented provide a basis on which to estimate the potential for modified screens to meet the Clean Water Act Phase II §316(b) national performance standard for impingement mortality reduction (80–95%).

Background

Data from laboratory, prototype, and full-scale studies of modified traveling screens have demonstrated that survival of fish is specific to species, life stage, and site, making it difficult to estimate survival of species that have not been tested with modified traveling screens. Intra-specific differences in survival observed among study sites also make it difficult to project an accurate and reliable estimate of survival at a new site where the screens have not been previously evaluated. Many studies of impingement survival have been performed. Yet, gaps remain in available data that need to be filled before it can be used to make accurate predictions of survival at cooling water intake structures (CWIS) where this technology is being considered to meet the §316(b) performance standard. In the 1990s, improvements were made to the screen design that minimizes collection and transfer stress and injury to fish. To date, the newer screen design has been installed and evaluated at only a few CWIS, primarily on estuaries and tidal rivers. As a result, there is little survival data available for the new screen design for species impinged at CWIS located on freshwater lakes and rivers.

Objectives

- To characterize the species-specific behavior of fish interacting with modified traveling screens.
- To characterize the rate at which impingement occurs and determine whether there is a variation in survival based on time swimming prior to impingement.
- To quantify the effect of approach velocity on species-specific fish survival.
- To assess the post-impingement survival of previously untested species.
- To document the type and frequency of injuries to fish that occur following removal from modified traveling screens.
- To investigate the effect of fish length on post-impingement survival.

Approach

To evaluate these objectives, the project team installed a state-of-the-art modified traveling screen in a large test flume. Injury, scale loss, and survival of 10 species of freshwater fish exposed to the impingement and collection process were evaluated. In addition, tests exposing fish to longer impingement durations, representative of what might be encountered at a typical CWIS, were conducted to assess the impact of extended impingement on injury, scale loss, and survival.

Results

Survival for all species and velocities tested exceeded 95%. In most cases, velocity was not significantly correlated to survival. For many species, survival was significantly correlated to fish length, with larger fish surviving better than smaller fish. With the exception of white sucker and fathead minnow, injury rates were low. These two species showed substantially higher injury. However, white sucker and fathead minnow exhibited higher control injury, indicating that the increased prevalence of higher injury rates was not a result of exposure to the screen. Scale loss showed the most consistent response across species. The majority of species had valid logistic regressions showing a pattern of significantly more scale loss at 0.61 m/s (2 ft/s) and 0.91 m/s (3 ft/s) compared to the control, but not at 0.30 m/s (1 ft/s). Given the high survival at velocities up to 0.91 m/s (3 ft/s), this technology has potential for wide-scale application to meet the Phase II §316(b) impingement mortality reduction standard.

EPRI Perspective

This report provides CWIS and other water intake operators with information on the ability of modified traveling screens to maximize impingement survival of juvenile and adult freshwater fish. Research results will allow water intake designers to configure these screens for optimal effectiveness and will allow resource managers to more accurately predict the potential for biological effectiveness of this technology at a given site.

Keywords

Fish protection technologies
Cooling water intake structures
Clean water act section 316(b)
Modified traveling screens
Ristroph screens

ABSTRACT

Modified traveling screens are a technology that can be considered for meeting the Clean Water Act Phase II §316(b) impingement mortality reduction standard. There is a substantial body of biological efficacy data available from installations of this technology in estuaries and tidal rivers. However, very little data exists for many of the species commonly impinged at cooling water intake structures (CWIS) located on freshwater rivers and lakes. Therefore, this study was undertaken to gather the additional information needed to support the application of this technology at freshwater CWIS.

The survival, injury, and scale loss rates of 10 species of freshwater fish impinged and recovered with a modified traveling screen were evaluated in the laboratory. Species tested included: golden shiner (*Notemigonus crysoleucas*); fathead minnow (*Pimephales promelas*); white sucker (*Catostomus commersoni*); bigmouth buffalo (*Ictiobus cyprinellus*); channel catfish (*Ictalurus punctatus*); hybrid striped bass (*Morone chrysops* × *M. saxatilis*); bluegill (*Lepomis macrochirus*); largemouth bass (*Micropterus salmoides*); yellow perch (*Perca flavescens*); and freshwater drum (*Aplodinotus grunniens*).

Fish were impinged at 0.30, 0.61, or 0.91 m/s (1, 2, or 3 ft/s) velocity. Survival rates exceeded 95% for all species and velocities tested, indicating that this technology has potential to meet the Phase II §316(b) impingement mortality reduction standard. Despite a general trend toward greater survival at lower velocities, velocity was only a significant factor in survival for bluegill.

Injury and scale loss rates were low for most species tested. Fish length played an important role in survival, injury, and scale loss. There was a trend toward increasing survival and decreasing injury and scale loss as fish grew larger. In all cases where fish length was a significant factor, the pattern of greater survival or less injury and scale loss as fish increased in length was observed.

Additional tests were undertaken with three species of fish to assess the effect of longer durations of impingement on survival, injury, and scale loss: channel catfish, fathead minnow, and golden shiner. Longer durations of impingement appeared to result in higher mortality, injury, and scale loss, especially at durations of impingement greater than 6 min. However, longer durations of impingement could be avoided at most CWIS by continuously rotating screens.

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1 INTRODUCTION

Modified traveling screens (commonly referred to as Ristroph screens) have the potential for wide-scale application in all regions of the country and in all waterbody types to meet the Clean Water Act Phase II §316(b) impingement mortality (IM) reduction standard (FR Vol. 69, No. 131, July 9, 2004)[1]. Modified traveling screens have advantages over many of the other impingement reducing options, because they:

- are relatively easy to retrofit at facilities that currently use traveling screens;
- can be cleaned automatically;
- do not interfere with navigation;
- do not alter aesthetics; and,
- will not generally require substantial civil/structural modifications or dredging except for the addition of a fish return line.

Hydraulic buffeting in the fish lifting buckets, identified as injurious to fish by Fletcher (1990), was reduced through improvements in bucket design during the 1980s and 90s (Figure 1-1). Evaluations of the latest generation of modified traveling screens have generally shown improved survival over previous screen designs. Examples include: Salem Generation Station (PSE&G 1999; PSEG 2004), Dunkirk Steam Electric Station[2] (Beak 2000a), Huntley Steam Electric Station (Beak 2000b), Indian Point (Fletcher 1990), and Arthur Kill Station[2] (Consolidated Edison 1996). For a full discussion of the historical modified traveling screen evaluations see EPRI 2006 – Chapter 1.

Data from laboratory, prototype, and full-scale studies of modified traveling screens have demonstrated that survival of fish is species-, life stage-, and site-specific, making it difficult to estimate survival of species that have not been tested with modified traveling screens. Intra-specific differences in survival observed between study sites also make it difficult to project an accurate and reliable estimate of survival at a new site where the screens have not been previously evaluated. Thus, while there have been many studies of impingement survival, there are many gaps in the available data that need to be filled before they can be used to make

[1] The Phase II rule calls for an 80-95% reduction in impingement mortality from the calculation baseline.

[2] The screens tested at Dunkirk and Arthur Kill were dual-flow screens, which are turned 90 degrees to the approach flow. Water enters a dual-flow screen through both the ascending and descending screen face. Like modified traveling screens, these dual-flow screens have fish lifting buckets, low pressure fish sprays, and a fish return. Post-impingement survival from dual-flow screens with fish handling modifications is similar to the modified traveling screens. As such, survival data from dual-flow screens is considered a good surrogate when data from modified traveling screens is lacking.

accurate predictions of survival at Cooling Water Intake Structures (CWIS) where this technology is being considered to meet the §316(b) performance standard. To date, the newer screen design has been installed and evaluated at only a few CWIS and primarily on estuaries and tidal rivers. As a result, there is little survival data available for the new screen design for species commonly impinged at CWIS located on freshwater lakes and rivers.

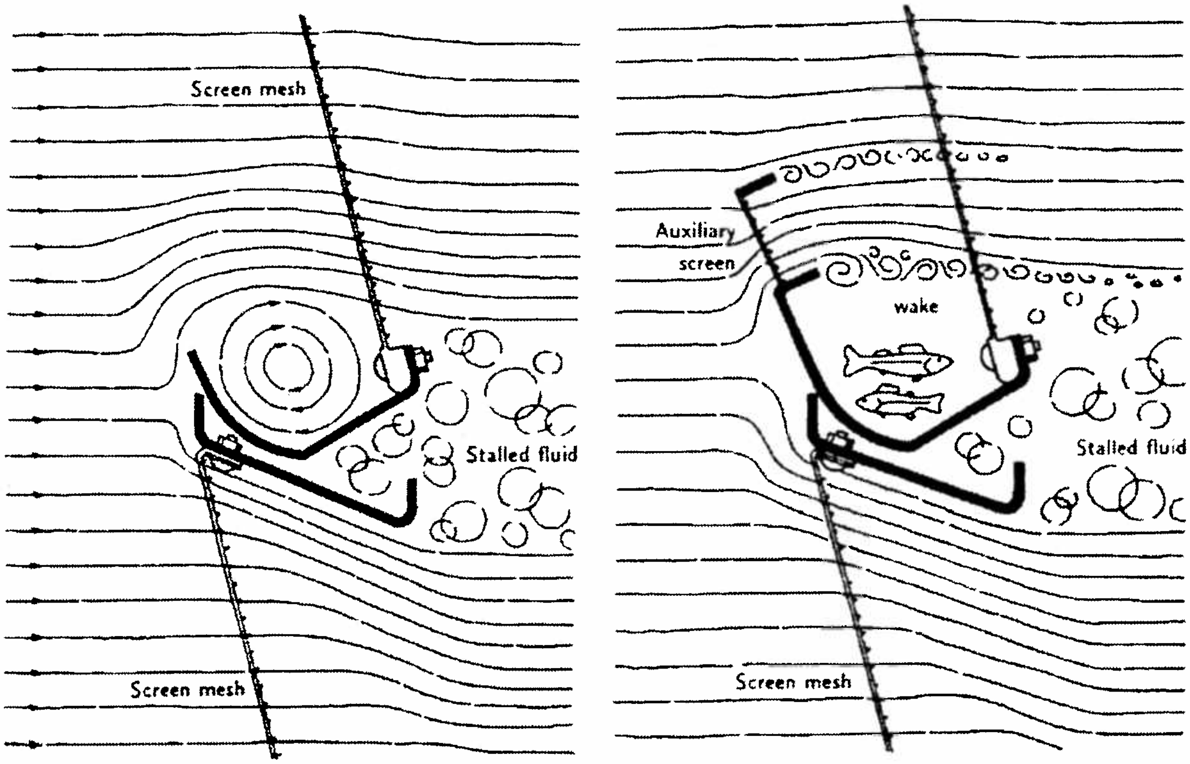

Figure 1-1
Composite Flow Profile through the Early and Improved Fletcher Modifications Showing the Calm Area within the Improved Bucket (Reproduced from Figures 7 and 8 in Fletcher 1990)

Typically, modified traveling screens are designed with a relatively low approach velocity (e.g., 0.30 m/s [1.0 ft/s]). At facilities where existing approach velocities are high (e.g., 0.91 m/s [3 ft/s]), redesigning the intake to meet a 0.30 m/s (1.0 ft/s) design criteria will require costly civil/structural or operational modifications. Under the Phase II §316(b) Rule, facilities would not be required to install a fish protection technology in cases when the economic benefits (saved fish) are not "significantly greater than" the costs to install and operate that technology. However, if fish survival at higher velocities (e.g., 0.46 m/s [1.5 ft/s] to as high as 0.91 m/s [3.0 ft/s]) is high, then these screens could be installed without additional CWIS modifications to reduce velocity. Therefore, if fish survival is high at velocities greater than 0.30 m/s (1.0 ft/s) with the numerically dominant species, and the dominant species are similar to those tested in the laboratory, then modified traveling screens would have a greater potential for meeting the impingement mortality reduction standard and passing the cost-benefit test at a greater number of facilities.

This study was undertaken by EPRI to:

- To characterize the species-specific behavior of fish interacting with modified traveling screens.
- To characterize the rate at which impingement occurs and determine whether there is a variation in survival based upon time swimming prior to impingement.
- To identify the species-specific variations in fish survival based upon the approach velocity.
- To assess the post-impingement survival of previously untested species.
- To document the type and frequency of injury to fish that occurs following removal from modified traveling screens.
- To investigate the effect of fish length on post-impingement survival.

An important aspect of the study was the visualization of fish behavior as they approach the screen, interact with it, collect in the buckets, and wash off into the collection trough. Past studies have generally not included video capture of behavior. The observations made in this study have contributed greatly to our understanding of the importance of fish behavior during the impingement process.

2
METHODS

Test Facility

Testing was conducted at Alden Research Laboratory, Inc. (Alden) in Holden, MA. A modified traveling screen was installed in the Alden Fish Testing Facility (Figure 2-1 and Figure 2-2). The 208 m^3 (55,000 gallon) capacity steel flume was equipped with a 150 hp bow thruster, which can produce velocities up to 0.91 m/s (3 ft/s). The flume was also equipped with a bag filter system to remove particulates and maintain water quality. The section of the flume where the testing was performed had a maximum depth of 2.0 m (6.5 ft) and a width of 1.8 m (6 ft).

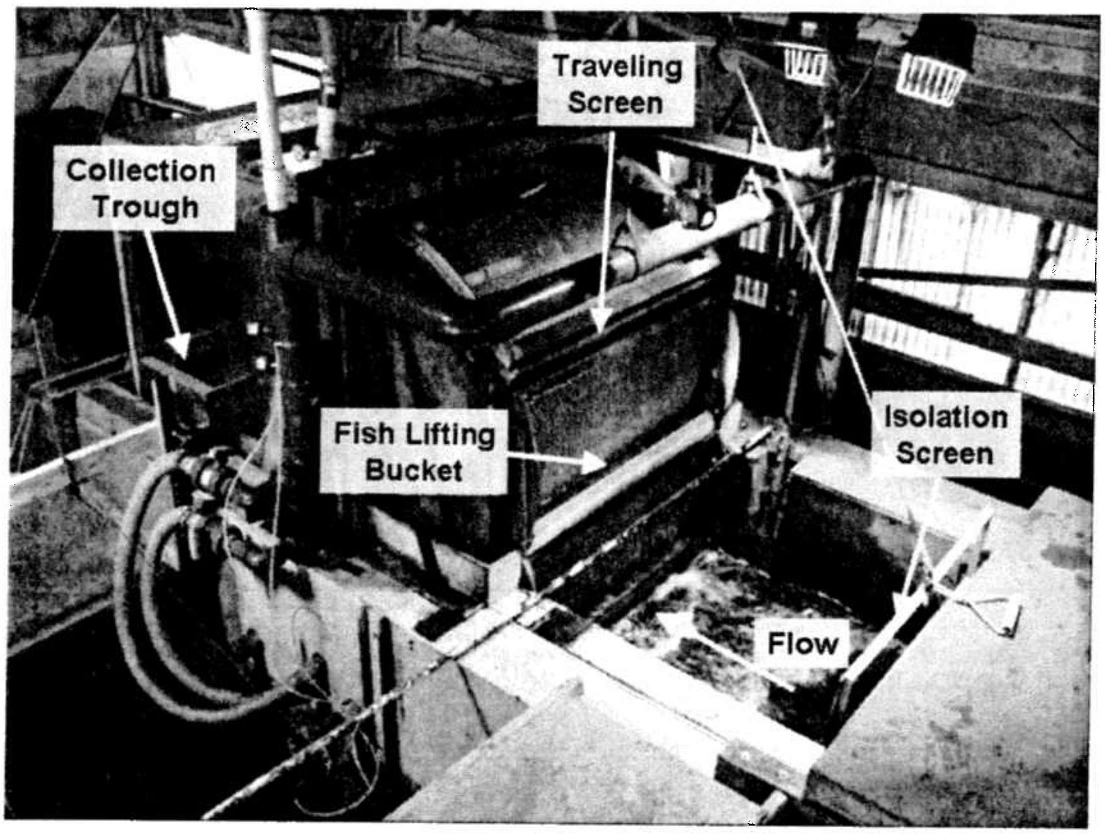

Figure 2-1
Overview of Modified Screen Testing Facility

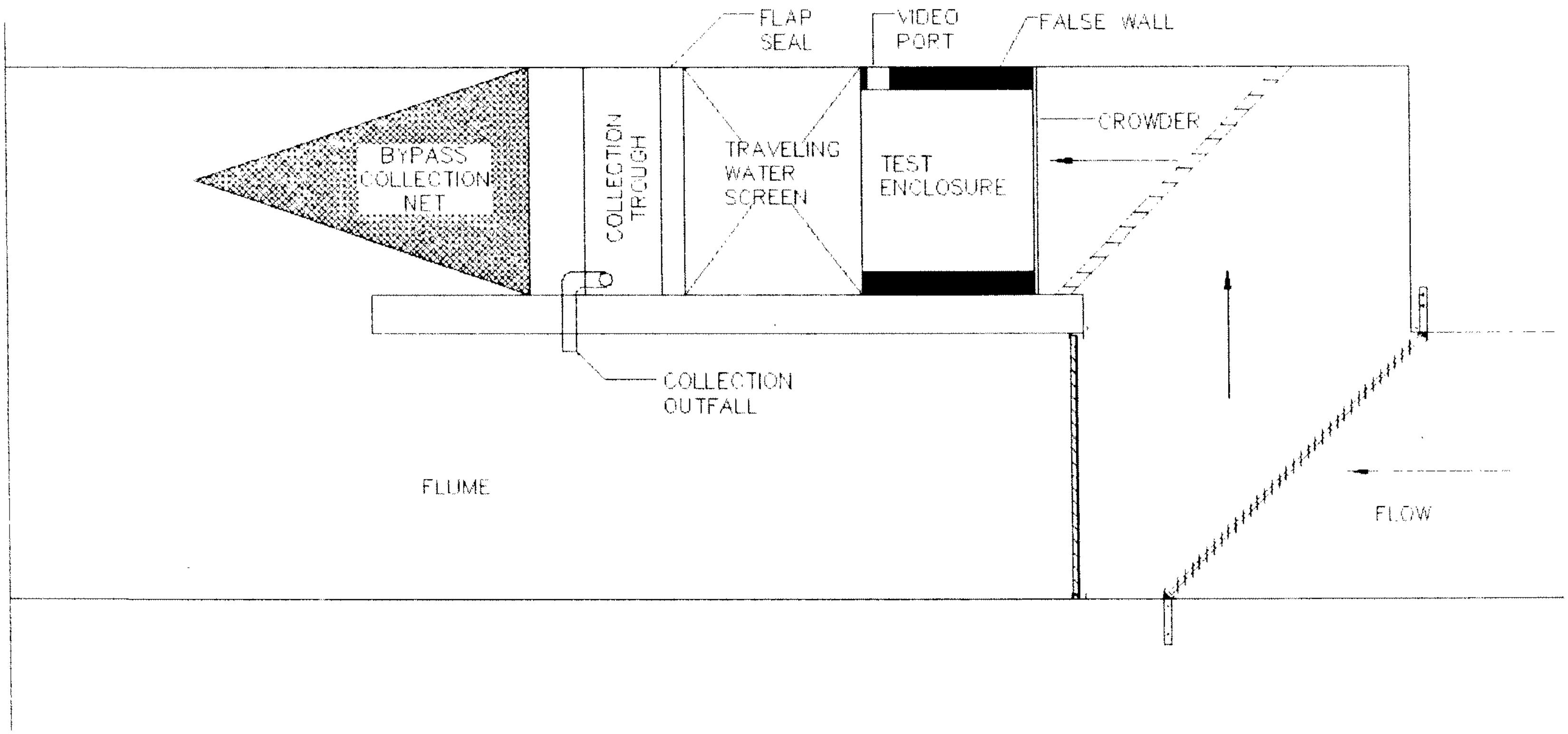

Figure 2-2
Plan View of the Test Flume with the Test Screen in Place

Biological tests within the flume were carried out using a small modified traveling screen (Figure 2-3). Screen baskets were 1.2-m (4-ft) wide and were equipped with 0.64 cm (0.25 in.) × 1.3 cm (0.5 in.) rectangular, smooth-tex mesh[2]. The pilot-scale screen was 2.4-m (8-ft) tall (1.8 m [6 ft] between the centerlines of the top and bottom screen sprockets) (Figure 2-4). The screen was designed to rotate at speeds ranging from 2.4–10.4 m/min (8–34 ft/min). The boot section of the screen was equipped with a brush device to prevent fish from passing underneath the screen. The screen had a fish and debris spraywash/return system, which included spraywash headers (one external and two internal pairs), a neoprene rubber flap seal, and a simulated section of a return trough on the downstream side of the screen. Atypical of modern screen designs, a single debris/fish trough was used because height limitations prohibited the use of dedicated fish and debris troughs. Other than the fish trough and height of the pilot-scale screen, the following features of the screen were identical to screens that would be installed at CWIS:

- basket dimensions,
- gaps between the baskets,
- spaces between the baskets and the screen frame,
- spraywash nozzle orientation and water pressure, and
- the distance between the flap seal and the screen face met manufacturer's full-scale design specifications.

Each of these design elements was critical to successfully create the exact conditions that fish experience as they interact with traveling water screens at CWIS.

[2] The screen baskets used were previously used at the Salem Generating Station on the Delaware River. The baskets were shortened to 4 ft length.

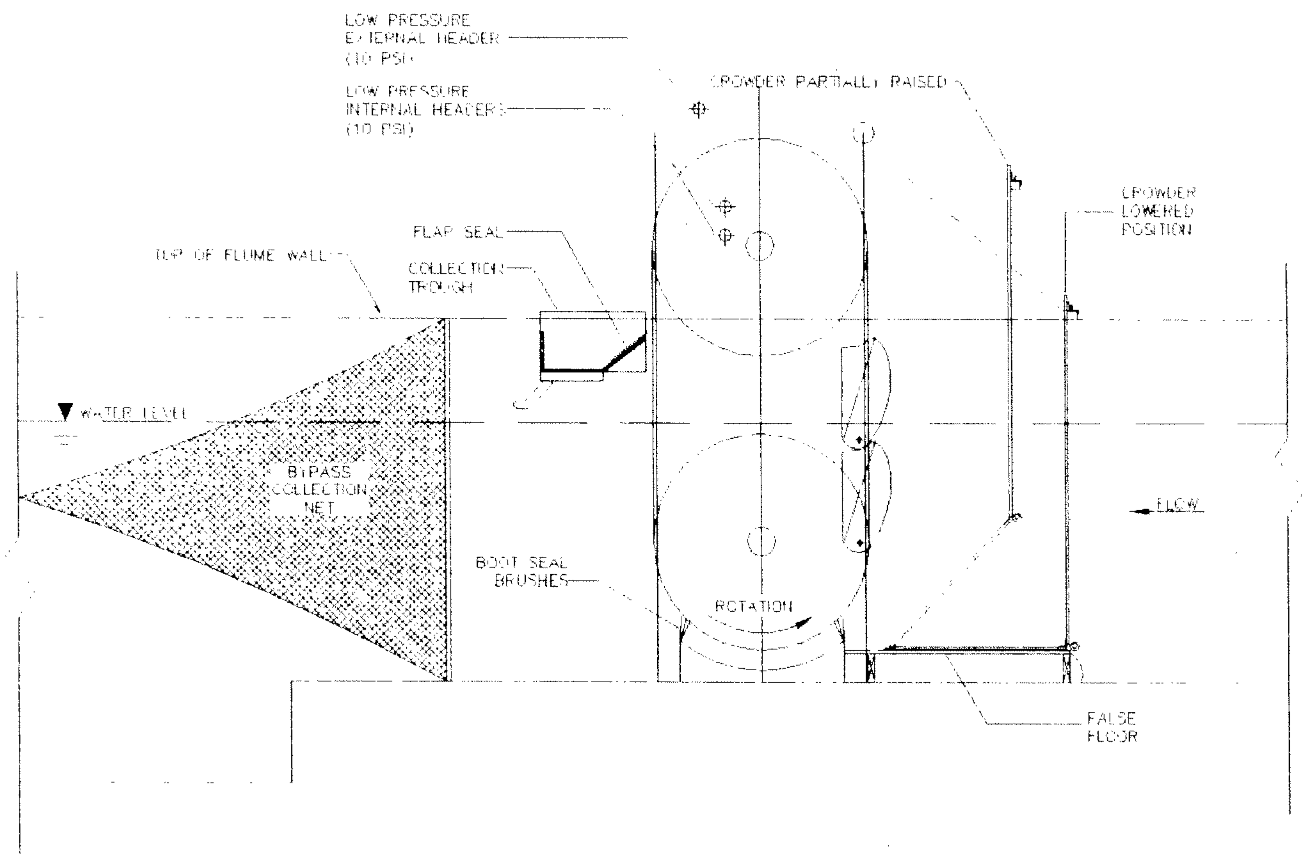

Figure 2-3
Section View of the Test Flume Including Traveling Water Screen and Collection Net

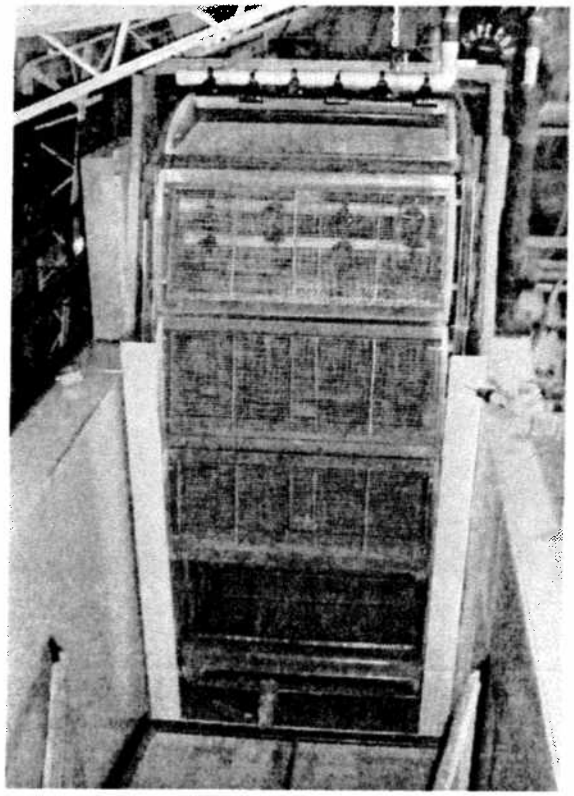

Figure 2-4
Modified Traveling Screen in the Dewatered Test Flume

Fish Holding Facility

The fish holding facility consisted of, a 20,820-liter (5,500-gallon) recirculating system (Figure 2-5). Fish were held in one of eight cylindrical tanks, which drain into a central pool. Water was pumped through water treatment filters before returning to the holding tanks and completing the loop. Bag filters and an activated charcoal filter were used to remove particulates (solid waste material and other impurities). An ultraviolet light sterilizer and a fluidized bed (sand) bio-filter were used to control bacteria and soluble waste products. The holding facility was equipped with a five ton chiller to maintain water temperatures. Water quality (dissolved oxygen, temperature, and salinity) were monitored daily. Salinity levels were maintained at approximately 5 ppt to reduce the occurrence of fungal growth common in freshwater systems. Hardness, alkalinity, and ammonia levels were monitored weekly.

Circular flow patterns were maintained in the fish holding tanks to keep fish active and reduce contact with the tank walls that could cause scale loss. Fish were fed age-, size-, and species-specific diets, which included dried brine shrimp, live *Artemia* sp., and solid commercially available fish chow. Fish physiology and behavior was qualitatively assessed daily to screen for external signs of disease, fungus, or infection by parasites.

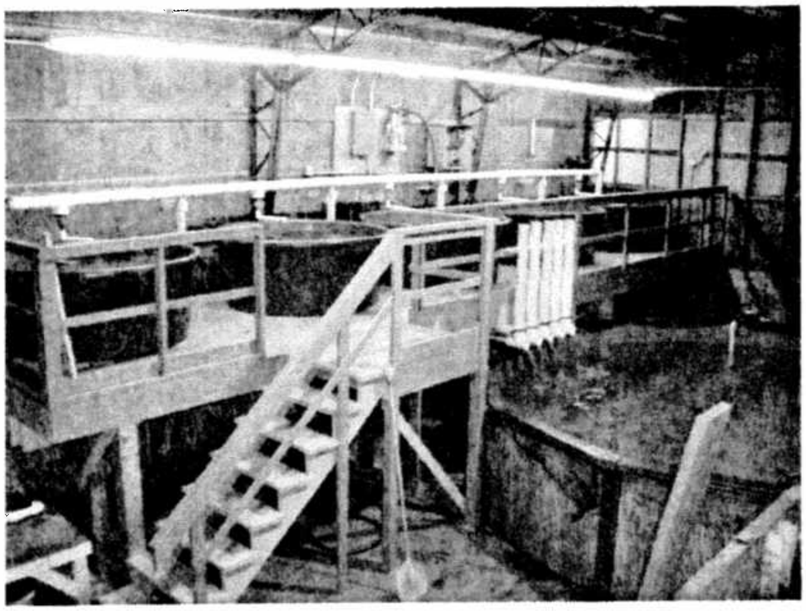

Figure 2-5
Fish Holding Facility

Velocity Measurements

Velocity measurements were recorded at the beginning of the experiments to verify that the flume operating conditions produced the desired approach velocities with a relatively uniform distribution upstream of the traveling screen. Velocity measurements were used to develop a predicted bow thruster output curve, such that bow thruster rpm could be used to set the approach velocity for each test.

Test Species

Ten species were tested during the evaluation: candidate species were considered for evaluation based on a query of EPRI's Entrainment and Impingement Database (EIDB) for freshwater species, the occurrence and abundance at CWIS, and a lack of survival data from existing modified traveling screens. A database of traveling screen survival data, which includes studies from multiple screen types, was queried and gaps in impingement survival data were identified. The final selection of test species was based on the following criteria:

- they commonly occur at many power plant intakes;
- they are relatively abundant in impingement samples (i.e., they do not have life history characteristics that would limit the likelihood that they would ever be susceptible to impingement);
- they represent important recreational or commercial species; and/or
- they are readily available for test purposes.

Based on discussions with hatcheries and other suppliers, species listed in Table 2-1 were selected for evaluation. Attempts were made to obtain gizzard shad, a species that occurs in great abundance at many CWIS. Gizzard shad were trucked along with bigmouth buffalo and freshwater drum from Missouri to Massachusetts. While survival of bigmouth buffalo and freshwater drum was high, almost none of the gizzard shad survived transport. As a result, gizzard shad were not tested and hybrid striped bass were substituted.

Table 2-1
Species Selected for Evaluation

Family	Common Name	Scientific Name
Cyprinidae	golden shiner	*Notemigonus crysoleucas*
	fathead minnow	*Pimephales promelas*
Catostomidae	white sucker	*Catostomus commersonii*
	bigmouth buffalo	*Ictiobus cyprinellus*
Ictaluridae	channel catfish	*Ictalurus punctatus*
Percichthydiae	hybrid striped bass	*Morone chrysops x M. saxatilis*
Centrarchidae	bluegill	*Lepomis macrochirus*
	largemouth bass	*Micropterus salmoides*
Percidae	yellow perch	*Perca flavescens*
Sciaenidae	freshwater drum	*Aplodinotus grunniens*

Fish Marking

Twenty-four hours or more prior to testing, a New West POW'R-Ject marking gun was used to mark 300 treatment and 100 control fish of each species being tested (Figure 2-6). The marking system uses compressed CO_2 to inject biologically inert, micro-encapsulated photonic dye at the base of individual fins. Injection pressure and dye volume were adjusted to facilitate marking different species and sizes of fish. Four colors and three fin locations were used to provide 12 unique marks, which allowed the resulting combination of color and fin location to be used once per week (based on four replicates per day × three testing days per week). Uniquely marked release groups allowed fish to be identified to the replicate from which they were released, regardless of when they were collected. Marking fish in this way was very effective. Of the 15,721 fish collected by impingement, only 67 fish (0.4%) did not have discernable fin marks.

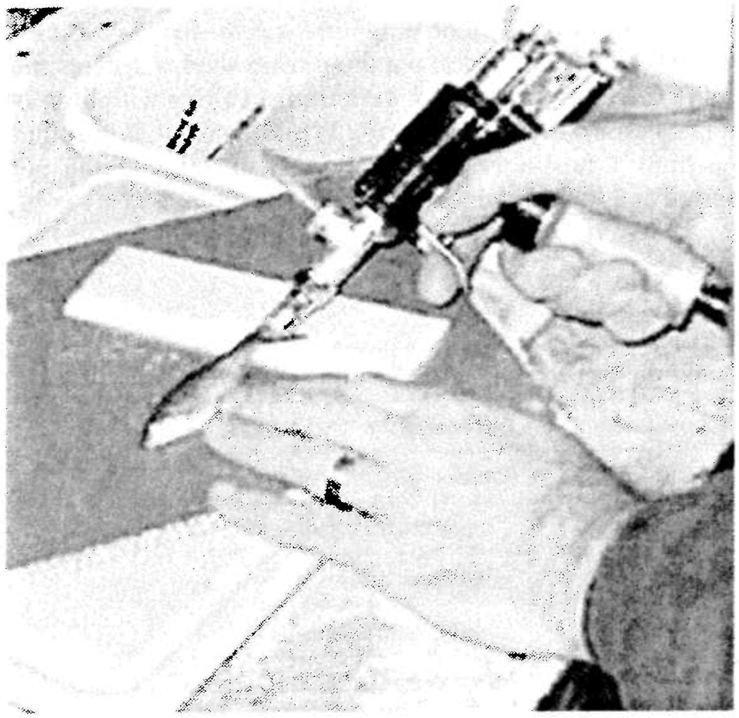

Figure 2-6
Marking Fish Using Marking Gun

Experimental Design – Velocity Tests

The post-impingement survival of fish following exposure to modified traveling screens was assessed. It was anticipated that survival would be variable depending upon species and approach velocity. It should be pointed out that the impingement experience with modified traveling screens is different than the impingement experience with conventional traveling screens. On conventional traveling screens, the screen face is perpendicular to the flow and there is no refuge for fish until they are removed from the flow. By contrast, each screen panel on the modified screen tested is slightly inclined to the flow. This slight incline appeared to help fish move toward the fish bucket (Figure 2-7). However, the extent to which this incline reduces the potential for mortality is unknown.

The length of time swimming prior to impingement and the impact of fish size (length) on impingement rates and survival was also evaluated. Finally, qualitative observations of fish behavior as they encounter the traveling screen were made using underwater video cameras (Figure 2-8).

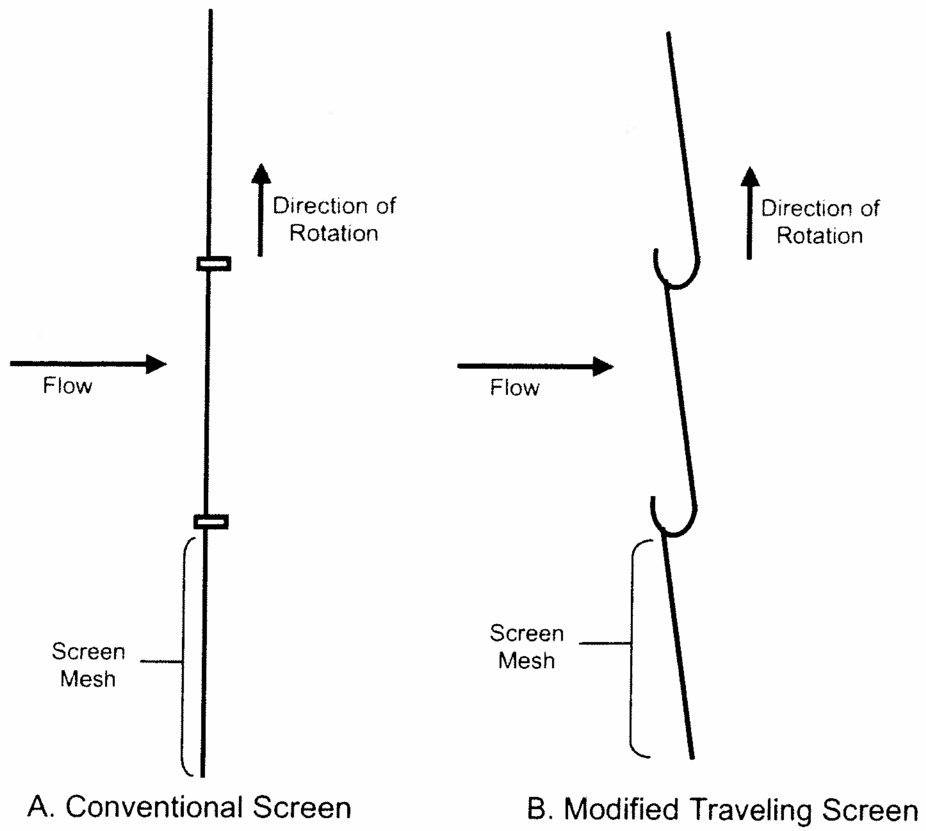

Figure 2-7
Comparison of a Conventional Screen (A) to a Modified Traveling Screen (B) Showing the Angle of the Screen Faces to the Approaching Flow

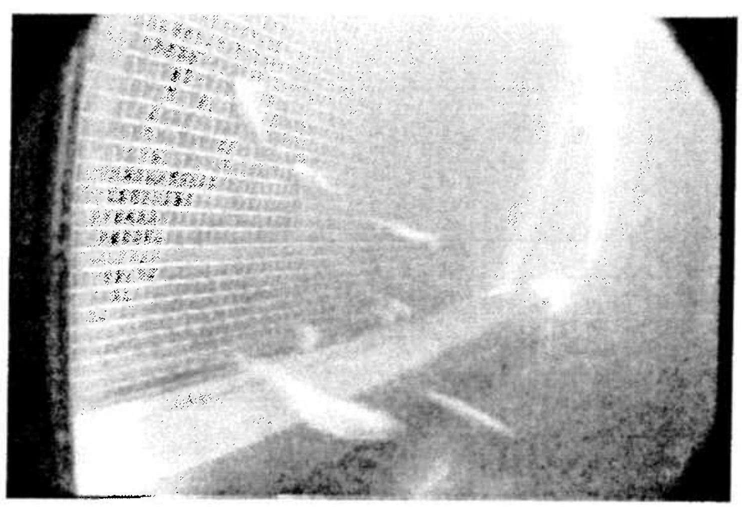

Figure 2-8
Still Image Capture from the Submersible Video Camera Showing Fish Impingement on the Traveling Water Screen

The following test conditions were evaluated:

- species (ten)
- approach velocity (0.30, 0.61, and 0.91 m/s [1.0, 2.0, and 3.0 ft/s])

The approach velocities selected bracket the range of velocities typically observed at CWISs (0.30 to 0.91 m/s [1.0 to 3.0 ft/s]). A database of design and operation data from many CWISs was analyzed to determine typical water velocities approaching traveling water screens. Data from 88 CWISs using once-through cooling were used in the analysis. These facilities were selected for analysis because the reports provided by power companies had the necessary information to calculate approach velocities. The calculated velocities were based on CWIS design information, and it was assumed that the intakes were operating at design intake flow (all pumps operational) at expected low water depth. Thus the calculated velocities represent the expected highest velocity approaching the traveling water screens. The intakes evaluated were located nationwide and represent all major waterbody types (freshwater lakes and rivers, estuaries, marine, and Great Lakes). Results of the analysis indicated that the mean approach velocity at existing plants is 0.30 ft/s (0.98 ft/s), with a median value of 0.27 m/s (0.9 ft/s) and a range of 0.09 m/s (0.3 ft/s) to 0.82 m/s (2.7 ft/s).

For each species, three test velocities with five replicates per test were conducted. Three test conditions and one handling control for each test were undertaken three days per week (Figure 2-9). A randomized design was used to determine the order of testing. On each day of testing, a control group was tested to separate mortality associated with handling (removal from holding facility, marking, counting into test groups, and introduction to and removal from the test flume). Control groups were randomly assigned a timeslot on each test day to ensure that control groups were not tested at the same time each day.

Water temperatures were recorded for most testing days.

Monday	Tuesday	Wednesday	Thursday	Friday	Weekend
Test Day 1 (A_{1-3} & $Control_1$)	Test Day 2 (B_{1-3} & $Control_2$)	Test Day 3 (C_{1-3} & $Control_3$)			
	24-hr Latent Mortality (A_{1-3} & $Control_1$)	**24-hr Latent Mortality (B_{1-3} & $Control_2$)**	**24-hr Latent Mortality (C_{1-3} & $Control_3$)**		
		48-hr Latent Mortality (A_{1-3} & $Control_1$)	48-hr Latent Mortality (B_{1-3} & $Control_2$)	48-hr Latent Mortality (C_{1-3} & $Control_3$)	
Mark 400 Fish for Test Day 2	Mark 400 Fish for Test Day 3			**Mark 400 Fish for Test Day 1 (Monday)**	
Fish Care	Fish Care	Fish Care	Fish Care	Fish Care	Fish Care
Water Quality Monitoring	Water Quality Monitoring	Water Quality Monitoring	Water Quality Monitoring	Water Quality Monitoring	Water Quality Monitoring

Figure 2-9
Weekly Testing, Water Sampling, and Fish Care Schedule

Experimental Design – Impingement Duration Tests

It has long been assumed that longer impingement durations contribute to greater injury, scale loss, and/or mortality. Therefore, it was deemed important in this study to investigate extended impingement durations. Assuming continuous operation of the screens and fish impingement occurring at the bottom of the screen well, the duration of impingement would typically range from 30 seconds to 12 minutes. Since water depth in the test flume was limited to 1.5 m (5 ft), the maximum duration of impingement (DI) for fish during the velocity tests was about 40 seconds (assuming 2.4 m/s [8 ft/min] rotation speed and fish impinged at the deepest point in the flume). Therefore, it was not possible to evaluate longer durations of impingement during velocity tests while maintaining continuous screen rotation, a feature generally considered as important to fish survival.

The initial study design of the velocity tests involved two screen rotation speeds; however, the extremely slow rotation speed necessary to achieve longer durations of impingement had a substantial drawback. Observing the impingement of fish at 2.4 m/s [8 ft/min] rotation speed indicated that there was a behavioral component to the impingement process. In many cases, fish would hold position in the flume and fall back to the screen surface until their tails touched the screen face. The tail touching would, in turn, stimulate the fish to swim forward again. This "tail-tapping" often occurred several times before the fish entered the bucket. Once in the calm conditions in the bucket, fish typically remained there. Since the investigation sought to evaluate the entire screening process from impingement, through the spray-wash, and finally transfer to the return trough, it was deemed necessary to continuously rotate the screen. In addition, since modified traveling screens are designed to rotate continuously in the field, rotating continuously in the laboratory is representative of field conditions relative to fish behavior. Therefore, a second set of tests were undertaken specifically to simulate longer impingement durations. For these tests, fish were introduced at a high velocity (0.91 m/s [3 ft/s]) while the screen remained stationary for a set amount of time (2, 4, 6, 8, or 10 minutes) to simulate longer durations of impingement. Early test results showed little injury and no mortality at durations of 2 and 4 minutes. Therefore, these conditions were dropped from further testing to maximize the use of a limited number of available test organisms and the remaining tests were conducted at the longer impingement durations.

The initial selection of impingement durations to be tested was based upon data from existing CWIS, which were calculated for a large number of power plants. Values were calculated for 56 CWIS representing 39 power plants. The average calculated DI was 2.8 minutes SE = (± 0.26), with a median value of 2.1 minutes. The minimum and maximum durations of impingement were 0.5 and 12 minutes, respectively.

The number of fish tested and the number of replicates completed was determined by availability. A total of 40 test and control replicates were run with channel catfish (12 replicates; n=446), golden shiner (12 replicates; n=262), and fathead minnow (16 replicates; n=332). A randomized design was used to determine the order of testing. For each set of treatment replicates, control groups were tested to separate mortality associated with handling (removal from holding facility, marking, counting into test groups, and introduction to and removal from the test flume). Control groups were randomly assigned a timeslot on each test day to ensure that control groups were not tested at the same time each day.

Procedures

Velocity tests were conducted in the following way:

1. The screen rotation speed and spraywash pressure were set. The approach velocity was initially set at 0.15 m/s (0.5 ft/s). The isolation screen[+] that confined fish to the traveling screen area was lowered into place.
2. A floating net collection pen was placed at the discharge of the return trough.
3. During testing, observations of fish behavior were recorded using underwater cameras to determine if a pattern exists in the way that fish interact with the screen under the various test conditions. The first 15 minutes of each replicate was videotaped for future analysis.
4. When conducting a control replicate, 100 marked fish of each species being tested was released into the fish return trough. Once the fish were oriented to the flow, a knife gate at the discharge was removed and the fish were allowed to sluice into a net pen.
5. When conducting a treatment replicate, 100 fish of each species were introduced just upstream of the traveling screen in the test enclosure (Figure 2-10) at the previously-set 0.15 m/s (0.5 ft/s) velocity. Once the fish were swimming normally, the velocity was increased rapidly to the target test velocity.

[+] The isolation screen doubles as a mechanical crowder at the end of each test replicate (see Step 8, below).

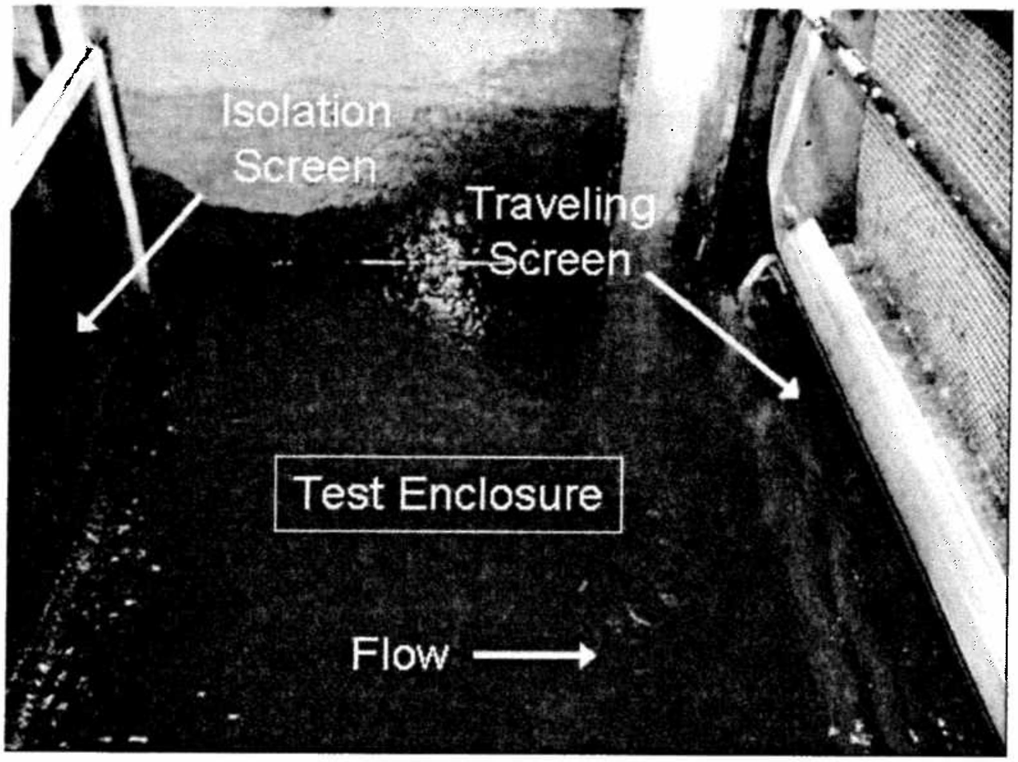

Figure 2-10
Test Enclosure Showing Upstream Isolation Screen (Left) and the Ascending Face of the Traveling Water Screen (Right)

6. Fish that impinged on and were washed from the screen were held in the fish collection trough and subsequently sluiced into the floating net pen, located at the discharge of the return trough, at set intervals of 15, 60, and 120 minutes.
7. Immediately following each collection, fish were observed and assigned into one of three categories:
   a. Live fish – swimming normally, with no signs of injury, apparent orientation problem, or abnormal behavior.
   b. Stunned fish – struggling, swimming on side, floating belly-up but alive, bleeding or the presence of wounds, missing body parts, severe abrasions or lacerations. Live specimens and stunned fish were held in pens to assess latent impingement mortality (LIM).
   c. Dead fish – no vital signs, no body or opercular movement, no response to gentle probing.
8. Following the 120 minute collection, the water velocity was reduced to 0.30 m/s (1 ft/s) and the mechanical crowder was raised to move fish that were still swimming upstream of the screen into the screen collection buckets (Figure 2-11).

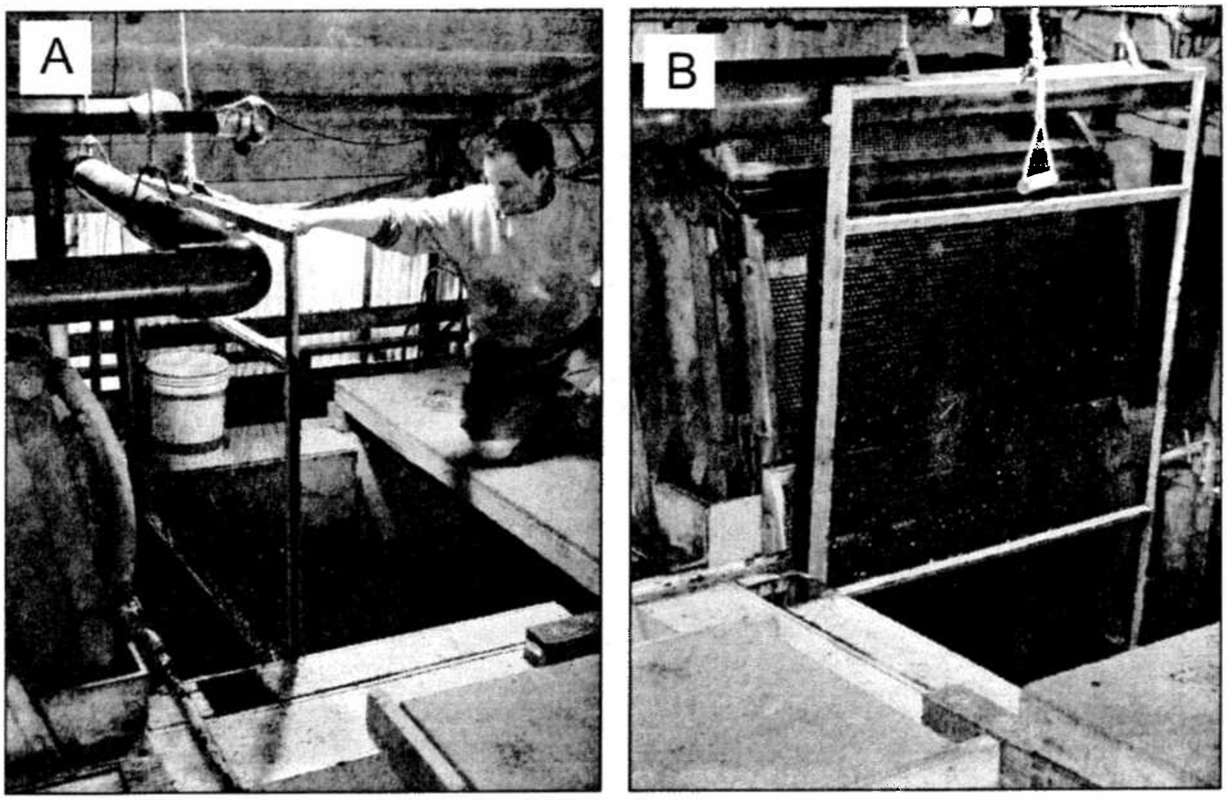

Figure 2-11
Crowding Fish (A) and Mechanical Crowder in the Full Upright Position (B)

9. Fish that were entrained through the screen or were carried over the fish return during transfer were collected in the downstream collection net once per day at the end of testing, enumerated, and fork lengths (FL) measured to the nearest millimeter. The tails of freshwater drum are not forked, so total length was measured (TL).

10. At the end of each collection event, any fish recovered from the fish return trough (treatment or control replicate) were transferred back to the holding facility in individually marked net pens and held for LIM assessment (Figure 2-12).

11. Fish survival was monitored at 24- and 48-hours following impingement. At the end of 48-hours, all fish were euthanized and examined for external injuries and percent scale loss (Figure 2-13). External injuries were recorded by type: bruising/hemorrhaging, lacerations, severed body, eye damage. Using methods similar to those reported by Neitzel et al. (1985) and Basham et al. (1982), percent scale loss (< 3%, 3–20%, 20–40%, and > 40%) was recorded along the length of the body. All fish were measured for fork length to the nearest mm. Any fish unable to maintain equilibrium at 48-hours after testing was considered dead.

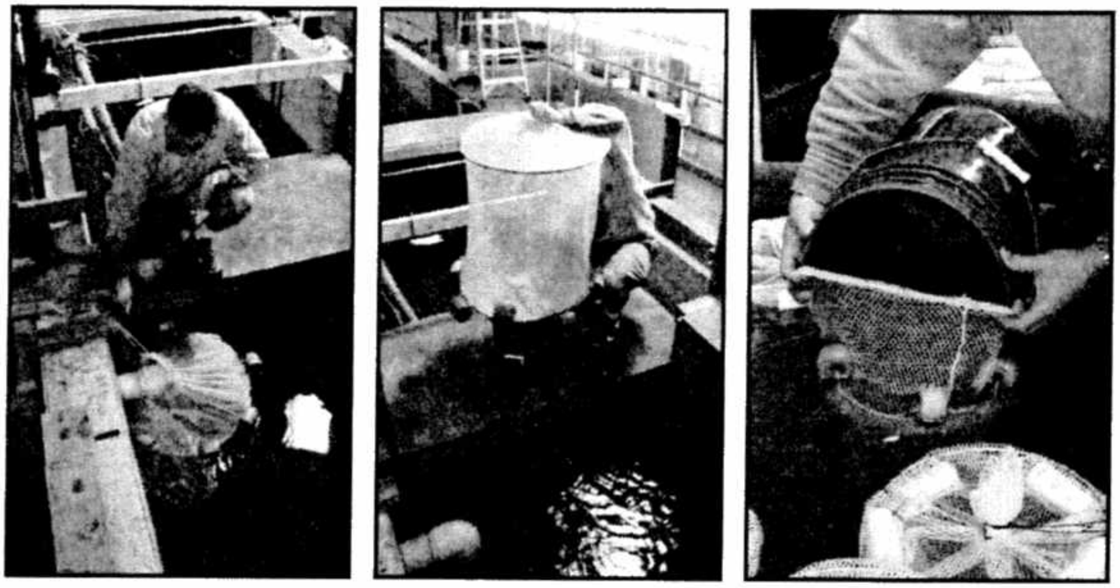

Figure 2-12
Fish Collection and Transfer to Holding Facility

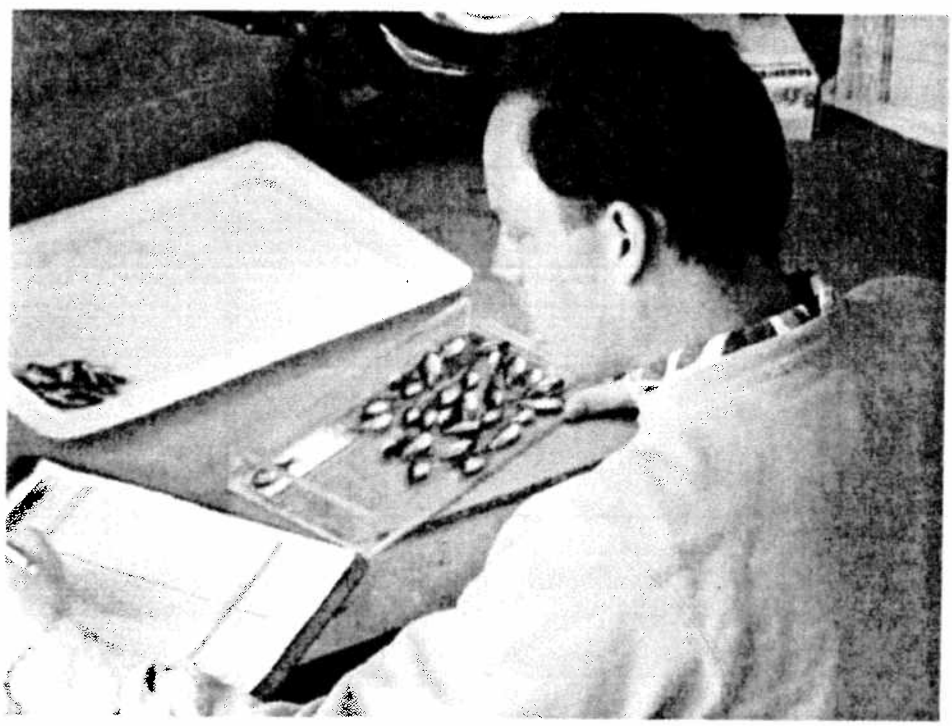

Figure 2-13
Measuring and Examining Fish for External Injuries

The method used to conduct DI tests were as follows:

1. The screen was held in position and the approach velocity was set at 0.91 ft/s (3.0 ft/s). This high velocity was used to maximize the number of fish impinged.
2. Marked fish were introduced just upstream of the screen face in the test enclosure (see Marking Fish – Velocity Tests for a description of the marking procedure).
3. For treatment replicates, fish were allowed to interact with the screen for 6, 8, or 10 minutes after introduction into the test enclosure.
4. At the end of the 6, 8, or 10 minute period, the screen was rotated until the screen panels that had been in the water were just above the water line.
5. For control replicates, fish were poured directly into a water filled bucket above the flume water line (Figure 2-14).
6. For both treatment and control replicates, fish were removed from the water-filled buckets using a small net and transferred to a water filled bucket for transport back to the holding facility.
7. Immediately following each collection, fish were observed and assigned into one of the three categories described previously.
8. Fish were transferred back to the holding facility, placed into individually marked net pens, and held for a 48-hour LIM assessment.
9. Fish survival was monitored at 24- and 48-hours intervals. At the end of 48-hours, all fish were killed and examined for external injuries and percent scale loss. Injury and scale loss were assessed in the same manner as previously described.

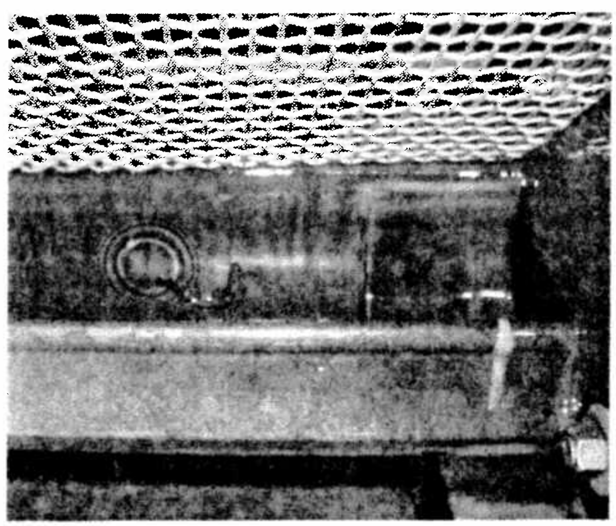

Figure 2-14
Fish in a Water Filled Bucket above the Flume Water Line

Data Analysis – Velocity Tests

Over 19,000 fish were tested. Of these, roughly 13,000 were used for data analysis. Of the remaining fish, the large majority were collected downstream of the screen (i.e., entrained or carried over the flap seal during transfer from the screen to the fish return trough). Others were either unaccounted for, did not have an identifiable mark, or were collected in a subsequent trial (Table 2-2).

Table 2-2
Numbers of Fish Released, Recaptured, Impinged, Collected Downstream, and Used for Data Analysis

Number of fish released	19,401
Number of fish impinged	14,665
Number of fish collected downstream	4,413
Total Number of fish collected through impingement or collected downstream	19,078
Number of fish unaccounted	323
Number of fish without identifiable marks	60
Number of fish collected in subsequent trial from the one in which they were released	1,596
Number of fish used for data analysis	13,009 (=14,665 - 60 -1,596)

Data were analyzed using non-linear logistic regression using SAS software (SAS Inst 1999), as outlined below.

Survival and Injury

The survival and injury data were analyzed using logistic regression. Four possible independent variables were analyzed:

1. approach velocity
2. collection time (15 minutes after introduction, 60 minutes after introduction, 120 hours after introduction, and crowd),
3. observation time (Initial, 24-hours, and 48-hours), and
4. fork length

Preliminary logistic regression models contained all four of the above variables; however, the impingement responses were not sufficiently distributed over two of these variables (collection time and observation time) to allow a simultaneous analysis. In the case of collection time, fish tended to remain upstream of the screen until crowding at lower velocities. Conversely, at higher velocities, the majority of fish tended to be impinged and collected during the first 15 minutes.

Thus, for any given velocity, the majority of fish fell into only one collection category. Similarly, very little mortality was observed during the initial and 24-hour observation periods. In all cases, this lack of identifiability between collection time and observation time prevented the logistic regression software from converging on reliable estimates. Therefore, the model design was reduced to include only the velocity and fork length as variables. This logistic regression analysis was implemented using the Logistic Procedure of the SAS software system (SAS Inst 1999).

Scale Loss

The analysis for scale loss was based on an extension of logistic regression to a multiple category response variable (McCullagh and Nelder 1989) where the categories were strictly ordered (Table 2-3).

Table 2-3
Scale Loss Categories

Scale Loss Category	Scale Loss Interval
1	<3%
2	3–20%
3	20–40%
4	>40%

For each treatment, the distribution of observations among the categories can be viewed as a cumulative distribution. The probabilities predicted by the model are the cumulative probabilities of the scale loss categories : p_1 = Pr(<=1) = Pr(= 1); p_2 = Pr(<=2) = Pr(= 1 or 2); p_3 = Pr(<=3) = Pr(= 1,2 or 3); and p_4 = Pr(<=4) = Pr(= 1,2,3 or 4) = 1.0. Note that p_4 is by definition 1.0 and so the model need only predict the first three. For each of these three probabilities, we formulate the standard logistic model:

$$p_{ijk} = e^{(\beta 0_i + \beta 1_j + \beta 2(L_k))} \Big/ \left\{1 + e^{(\beta 0_i + \beta 1_j + \beta 2(L_k))}\right\}$$

where:

p_{ijk} = cumulative probability i, for treatment j, for fish k.

$\beta 0_i$ = an intercept value for the first three scale loss categories, i = 1,2,3.

$\beta 1_j$ = a parameter for each velocity, j = 1,2,3. The control is modeled by the intercept and this parameter models the offset from the control for each velocity treatment.

$\beta 2$ = a coefficient for the effect of length.

L_k = fork length of fish k.

In this model, the term $\beta 0$ models the increase in probability from one cumulative probability to the next, and the $\beta 1$ term models a shift of the cumulative distribution from one velocity treatment to the next. This feature causes the predicted probabilities for one velocity treatment to be proportional to the predicted probabilities for another. That is, there is a constant odds ratio across scale loss categories between a pair of velocity treatments. For this reason, this model is sometimes called the "proportional odds model".

Data Analysis – Duration of Impingement Tests

Similar to the velocity tests described above, data were analyzed using logistic regression as outlined below.

Survival

The analysis for duration effects is based on logistic regression. In this analysis, duration was treated as a continuous variable rather than a categorical variable. That is, it was assumed that the effect of duration is monotonic and that its effect on the logarithm of the odds ratio can be quantified by a linear model. For analysis purposes, controls were assigned a duration time of zero. The model included both fork length and DI as independent variables.

Injury

The logistic regression of injury for the DI study included fork length and DI as factors. Analysis followed the methods outlined above of velocity tests, except that DI was treated as a continuous regressor variable whereas velocity was treated as a categorical variable.

Scale Loss

The methods for analyzing scale loss for DI effects were the same as those used for analyzing scale loss for velocity effects except that DI was treated as a continuous regressor variable whereas velocity was treated as a categorical variable.

3
RESULTS AND DISCUSSION

A total of 163 treatment and control replicates were tested over 33 days of testing between May 11 and August 24, 2005. Detailed discussions of mortality, injury, and scale loss are provided below. Observed post-impingement survival was high under all conditions tested (95% or greater). Mortality rates were higher at higher velocities, but this effect was significant only for bluegill. Injury rates were more variable by species, with significantly higher injury rates observed at higher velocities for many species. Velocity was also a significant indicator of scale loss for all six species with successful logistic regression models. Fish length played an important role in survival, injury, and scale loss. There is a trend toward increasing survival and decreasing injury and scale loss as fish grow larger. In all cases where fish length was a significant factor, the pattern of greater survival or less injury and scale loss as fish increased in length was observed.

Results of duration of impingement (DI) testing indicate that the mortality, injury, and scale loss were relatively low fish at durations of impingement less when DI was less than 10 minutes.

Water Temperatures

Water temperature can play an important role in post-impingement fish survival. Extremes in water temperature can lead to increased mortality. Recorded water temperatures during testing were 20°C ± 1 SE. Since temperatures and survival rates were fairly uniform, temperature likely did not impact the results of this study.

Fish Length

All fish tested were young-of-the-year and varied in length by species (Table 3-1).

Table 3-1
Mean Fork Length, Standard Error, and Length of Fish Used in Data Analysis

Species	Mean Fork Length (mm)	Standard Error	Length Range (mm)
Bigmouth Buffalo	72.1	± 0.255	35 – 91
Bluegill	47.6	± 0.193	27 – 105
Channel Catfish	64.2	± 0.167	41 – 99
Freshwater Drum[5]	84.7	± 0.217	41 – 104
Fathead Minnow	54.5	± 0.162	37 – 80
Golden Shiner	74.3	± 0.309	36 – 113
Hybrid Striped Bass	60.6	± 0.143	38 – 90
Largemouth Bass	98.5	± 0.295	71 – 161
White Sucker	79.8	± 0.348	46 – 148
Yellow Perch	49.7	± 0.267	32 – 88

Visual Observations

Underwater video recording and visual observations during testing revealed that the majority of fish encountered the modified traveling screen without "impinging" in the traditional sense. Most fish followed one of three paths to the bucket: 1) they impinged briefly on the screen mesh and wiggled across the screen surface to the bucket, while the screen basket was still submerged, 2) they tail tapped against the screen mesh until being scooped into the bucket near the water surface, or 3) they sought refuge in the relative hydraulic calm of the bucket without touching the screen face. These observations shed new light on the "impingement" process and suggest that modified Ristroph screens may be inherently less injurious to fish than previously assumed.

Time to Impingement

The number of fish collected at each velocity and for each collection time varied by species (Table 3-2). For most species, it appears that there was a threshold between 0.30 and 0.61 m/s (1 and 2 ft/s) at which fish could no longer maintain their position upstream of the screen. However, for most species a substantial number of fish were able to swim at 0.61 m/s (2 ft/s) for the duration of testing. At 0.30 m/s (1 ft/s), most fish were collected during the crowd, indicating that the fish were capable of swimming for 2 hours at the target velocity. At 0.91 m/s (3 ft/s), most fish were collected 15 minutes after introduction, indicating that they were unable to swim at this velocity for extended periods. Because fish tended to impinge either at low-velocity/long collection time or high-velocity/short collection time, it was not possible to separate the effects of velocity and collection time through statistical modeling.

[5] Freshwater drum do not have a forked tail. Therefore, total length (TL) was measured for this species.

Table 3-2
Frequencies of Fish Collected by Species, Collection Time, and Velocity Treatment

Species	Collection Time	0.30 m/s		0.61 m/s		0.91 m/s		Control Number
		N	%	N	%	N	%	
Bigmouth Buffalo	15 min	3	1.2	33	35.1	132	93.0	
	1 hr	3	1.2	3	3.2	5	3.5	
	2 hr		0.0		0.0	3	2.1	
	Crowd	239	97.6	58	61.7	2	1.4	
	Control							295
Bluegill	15 min	66	19.4	225	68.6	317	100.0	
	1 hr	11	3.2	17	5.2		0.0	
	2 hr	17	5.0	10	3.0		0.0	
	Crowd	246	72.4	76	23.2		0.0	
	Control							397
Channel Catfish	15 min	48	23.3	71	48.0	174	70.7	
	1 hr	58	28.2	26	17.6	40	16.3	
	2 hr	33	16.0	13	8.8	17	6.9	
	Crowd	67	32.5	38	25.7	15	6.1	
	Control							490
Freshwater Drum	15 min	15	6.2	46	20.0	203	99.5	
	1 hr	6	2.5	9	3.9		0.0	
	2 hr	9	3.7	10	4.3		0.0	
	Crowd	213	87.7	165	71.7	1	0.5	
	Control							512
Fathead Minnow	15 min	164	41.7	307	89.5	295	99.7	
	1 hr	25	6.4	16	4.7		0.0	
	2 hr	36	9.2	9	2.6	1	0.3	
	Crowd	168	42.7	11	3.2		0.0	
	Control							493

Table 3-2
Frequencies of Fish Collected by Species, Collection Time, and Velocity Treatment (Continued)

Species	Collection Time	0.30 m/s		0.61 m/s		0.91 m/s		Control Number
		N	%	N	%	N	%	
Golden Shiner	15 min	80	21.9	350	93.6	385	99.0	
	1 hr		0.0		0.0	4	1.0	
	2 hr	3	0.8		0.0		0.0	
	Crowd	282	77.3	24	6.4		0.0	
	Control							485
Hybrid Bass	15 min	13	5.3	16	6.6	270	75.8	
	1 hr	5	2.1	19	7.9	45	12.6	
	2 hr	13	5.3	26	10.8	21	5.9	
	Crowd	212	87.2	180	74.7	20	5.6	
	Control							498
Largemouth Bass	15 min	4	1.0	215	59.9	344	95.3	
	1 hr	1	0.3	5	1.4	4	1.1	
	2 hr	9	2.3	11	3.1	1	0.3	
	Crowd	380	96.4	128	35.7	12	3.3	
	Control							501
White Sucker	15 min	196	52.5	273	80.5	362	96.8	
	1 hr	25	6.7	22	6.5	9	2.4	
	2 hr	17	4.6	7	2.1	3	0.8	
	Crowd	135	36.2	37	10.9		0.0	
	Control							459
Yellow Perch	15 min	18	15.0	118	75.6	159	98.1	
	1 hr	10	8.3	10	6.4	3	1.9	
	2 hr	5	4.2	7	4.5		0.0	
	Crowd	87	72.5	21	13.5		0.0	
	Control							498

Velocity Tests

Survival

Review of the 48-hour survival data indicates that survival for all species was high regardless of approach velocity (Table 3-3). Confidence intervals were calculated using the binomial distribution. The results of the logistic regression models for survival are presented by species in Appendix A. A summary showing only pertinent p-values is presented in Table 3-4.

The logistic regression models are hierarchical. A flow diagram showing the steps described below is shown in Figure 3-1. To interpret the results, one should look first to the p-value for the entire model. If the model p-value is not significant (P>0.05), then one can conclude that none of the independent variables in the model have a significant effect. If the model is significant, then it is appropriate to look to the velocity and length components of the model. If the p-value involving length is significant ($P\leq$ 0.05), then a significant reduction in mortality, injury, or scale loss was observed as fish increased in length. In no cases did mortality increase with length. The models contain individual comparisons of the three velocity treatments to the control. When the p-value of velocity is not significant (P>0.05), then the individual comparisons should be interpreted as not significant. However, if the velocity component is significant ($P\leq$0.05), then it is appropriate to look at the individual velocity comparisons.

For bigmouth buffalo, mortality was very low and ranged from 0.0% for all three velocity treatments to 0.3% for the control (Table 3-3). There were too few mortalities with this species to perform a meaningful logistic regression (P=0.8233; Table 3-4).

For bluegill, mortality among the velocity and control treatments ranged from 0.9% at 0.30 m/s (1 ft/s) to 4.6% at 0.61 m/s (2 ft/s) (Table 3-3). These differences were significant (P=0.0005; Table 3-4). The 0.30 m/s (1 ft/s) treatment was not significantly different from the control while the 0.61 m/s (2 ft/s) treatment was significantly greater than the control (P=0.0004; Table 3-4). There was weak evidence that the 0.91 m/s (3 ft/s) treatment was different from the control (P=0.0601; Table 3-4). The length effect was significant (P<0.0001; Table 3-4) indicating a reduced likelihood of mortality as fish increase in size.

For channel catfish, mortality ranged from 0.0% for the 0.61 m/s (2 ft/s) treatment and the control to 1.0% for the 0.30 m/s (1 ft/s) treatment (Table 3-3). There were too few mortalities with this species to perform a meaningful logistic regression (P=0.6336; Table 3-4).

For freshwater drum, mortality ranged from 0.0% for the 0.30 m/s (1 ft/s) and 0.61 m/s (2 ft/s) velocity treatments to 0.5% for the 0.91 m/s (3 ft/s) velocity treatment (Table 3-3). There were too few mortalities with this species to perform a meaningful logistic regression (P=0.1903; Table 3-4).

For fathead minnow, mortality among the velocity treatments ranged from 1.2% in the control to 3.2% in the 0.61 m/s (2 ft/s) treatment (Table 3-3). These differences were not significantly different (P=0.2147; Table 3-4).

Table 3-3
Total Number of Fish Tested (n), Percent Alive 48 Hours After Testing, and the 95% Confidence Intervals (CI) by Species and Velocity. Survival was High for All Species and Conditions Tested and there was Considerable Overlap in the Confidence Intervals

Species	0.30 m/s (1 ft/s)			0.61 m/s (2 ft/s)			0.91 m/s (3 ft/s)			Control		
	n	% Alive at 48 H	95% CI	*n*	% Alive at 48 H	95% CI	*n*	% Alive at 48 H	95% CI	*n*	% Alive at 48 H	95% CI
Bigmouth Buffalo	245	100.0	NA[1]	94	100.0	NA	142	100.0	NA	295	99.7	98.7 – 100.0
Bluegill	340	99.1	97.8 – 99.9	328	95.4	92.9 – 97.5	317	97.8	95.9 – 99.2	397	98.5	97.0 – 99.5
Channel Catfish	206	99.0	97.3 – 99.9	148	100.0	NA	246	99.6	98.5 – 100.0	490	100.0	NA
Freshwater Drum	243	100.0	NA	230	100.0	NA	204	99.5	98.2 – 100.0	512	99.8	99.2 – 100.0
Fathead Minnow	393	97.7	96.0 – 99.0	343	96.8	94.7 – 98.4	296	98.3	96.5 – 99.5	493	98.8	97.6 – 99.6
Golden Shiner	365	98.4	96.8 – 99.4	374	98.7	97.2 – 99.6	389	98.5	97.0 – 99.5	485	98.8	97.6 – 99.6
Hybrid Bass	243	99.6	98.4 – 100.0	241	100.0	NA	356	99.7	98.9 – 100.0	498	100.0	NA
Largemouth Bass	394	99.0	97.7 – 99.8	359	97.8	96.0 – 99.1	361	97.2	95.3 – 98.7	501	99.2	98.2 – 99.8
White Sucker	373	95.7	93.4 – 97.6	339	95.3	92.8 – 97.3	374	95.5	93.1 – 97.4	458	96.9	95.2 – 98.4
Yellow Perch	120	99.2	96.9 – 100.0	156	97.4	94.4 – 99.3	162	98.8	96.6 – 99.9	498	99.0	97.9 – 99.7

[1] Confidence intervals could not be calculated for values of 100%

Table 3-4
Summary of Pertinent P-Values from the Maximum Likelihood Estimates for the Survival Regression Models for All Species Tested

Species	Model	Length	Velocity	0.30 m/s	0.61 m/s	0.91 m/s
Bigmouth Buffalo	0.8233	—	—	—	—	—
Bluegill	<0.0001[a]	<0.0001[a] ↓	0.0005[a]	0.8860	0.0004[a] +	0.0601 +
Channel Catfish	0.6336	—	—	—	—	—
Freshwater Drum	0.1903	—	—	—	—	—
Fathead Minnow	0.2147	—	—	—	—	—
Golden Shiner	0.0003[a]	<0.0001[a] ↓	0.7242	—	—	—
Hybrid Bass	0.9921	—	—	—	—	—
Largemouth Bass	0.0549	0.0773	0.1170	—	—	—
White Sucker	<0.0001[a]	<0.0001[a] ↓	0.7423	—	—	—
Yellow Perch	0.0392[a]	0.0052[a] ↓	0.3143	—	—	—

[a] Significant at α 0.05
↓ Mortality decreased with increasing fish length
+ = Significantly greater mortality than control

For golden shiner, mortality among the velocity treatments ranged from 1.2% in the control to 1.6% in the 0.30 m/s (1 ft/s) treatment (Table 3-3). These differences were not significantly different (P=0.7242; Table 3-4). There was evidence of a length effect (P<0.0001; Table 3-4). The negative coefficient indicates reduced likelihood of mortality as fish increase in length.

For hybrid striped bass, mortality was low and ranged from 0.0% for the 0.61 m/s (2 ft/s) treatment and the control to 0.4% for the 0.30 m/s (1 ft/s) treatment (Table 3-3). There were too few mortalities to perform a meaningful logistic regression (Table 3-4).

For largemouth bass, mortality among the velocity treatments ranged from 0.8% in the control to 2.8% in the 0.91 m/s (3 ft/s) treatment (Table 3-3). These differences were not statistically significant (P=0.1170; Table 3-4). There was weak evidence of a length effect (P=0.0773; Table 3-4). The negative coefficient indicates reduced likelihood of mortality at longer lengths.

For white sucker, mortality among the velocity and control treatments ranged from 3.0% in the control to 4.7% in the 0.61 m/s (2 ft/s) treatment (Table 3-3). These differences were not significantly different (P=0.7423; Table 3-4). There was evidence of a reduced likelihood of mortality as fish increase in length (P<0.0001; Table 3-4).

For yellow perch, mortality among the velocity treatments ranged from 0.8% in the 0.30 m/s (1 ft/s) treatment to 2.6% in the 0.61 m/s (2 ft/s) treatment (Table 3-3). These differences were not significantly different (P=0.3143; Table 3-4). There was evidence of a reduced likelihood of mortality as fish increase in length (P<0.0052; Table 3-4).

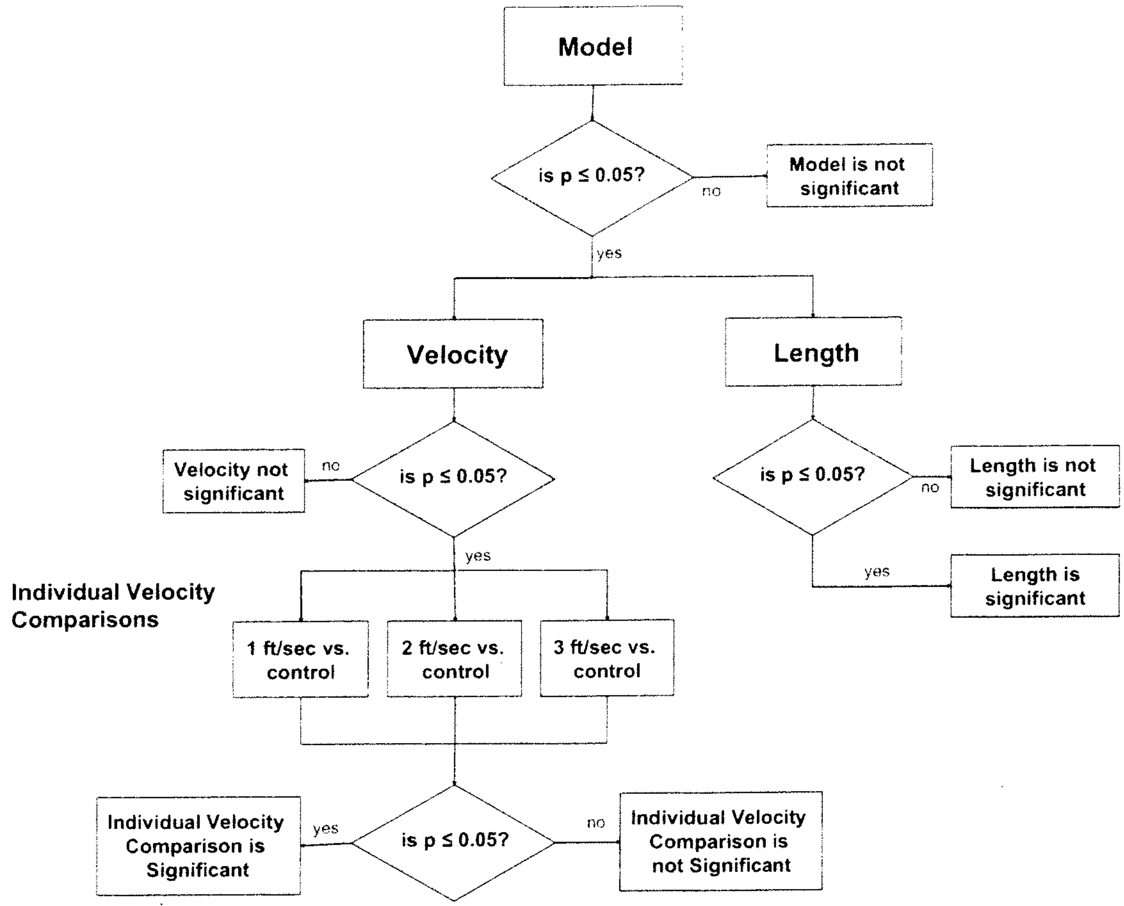

Figure 3-1
Interpreting the Hierarchical Results of the Logistic Regression Models

Injury

Review of injury data indicates that the rate of injury for all species was low regardless of approach velocity. Table 3-5 presents the rate of injury by species and velocity. During holding, some fish exhibited clear signs of disease. For example, fish that were swimming and behaving normally during the initial assessment would later be found dead, defined, descaled, and missing their eyes during the 24 or 48 hour assessment. We assumed these fish died as a result of predation rather than from interacting with the screen. Similarly, fish showing clear signs of fungus or other disease were recorded as diseased. Since disease and predation-related injury may not be a result of exposure to the screen, Table 3-5 provides injury rates excluding these types of injury.

The two wild-caught species (fathead minnow and white sucker) showed much higher rates of injury. However, the rates of control injury for these two species were also much higher, indicating that the higher rates of injury were not exclusively the result of screen exposure. The types of injury observed are shown on Figure 3-2.

Table 3-5
Percent Injury by Species and Velocity

Species	Velocity	Percent Injured	Percent Injured Excluding Disease and Predation
Bigmouth Buffalo	1	1.6%	1.6%
	2	1.1%	1.1%
	3	3.5%	3.5%
	Control	1.4%	1.0%
Bluegill	1	6.8%	6.8%
	2	9.5%	6.1%
	3	5.4%	4.4%
	Control	5.5%	2.0%
Channel Catfish	1	4.9%	2.9%
	2	0.0%	0.0%
	3	0.4%	0.0%
	Control	0.6%	0.4%
Freshwater Drum	1	0.0%	0.0%
	2	0.9%	0.9%
	3	0.0%	0.0%
	Control	1.0%	0.8%
Fathead Minnow	1	23.9%	17.0%
	2	22.7%	13.7%
	3	14.5%	5.4%
	Control	15.6%	8.1%
Golden Shiner	1	2.7%	2.5%
	2	4.8%	4.5%
	3	3.1%	2.1%
	Control	4.3%	3.7%
Hybrid Bass	1	0.0%	0.0%
	2	0.0%	0.0%
	3	0.3%	0.3%
	Control	0.0%	0.0%
Largemouth Bass	1	1.3%	0.5%
	2	10.0%	1.7%
	3	6.4%	0.8%
	Control	3.2%	0.0%
White Sucker	1	34.0%	27.6%
	2	29.8%	24.5%
	3	26.7%	21.7%
	Control	23.5%	19.6%
Yellow Perch	1	1.7%	1.7%
	2	1.9%	1.3%
	3	0.0%	0.0%
	Control	1.4%	0.6%

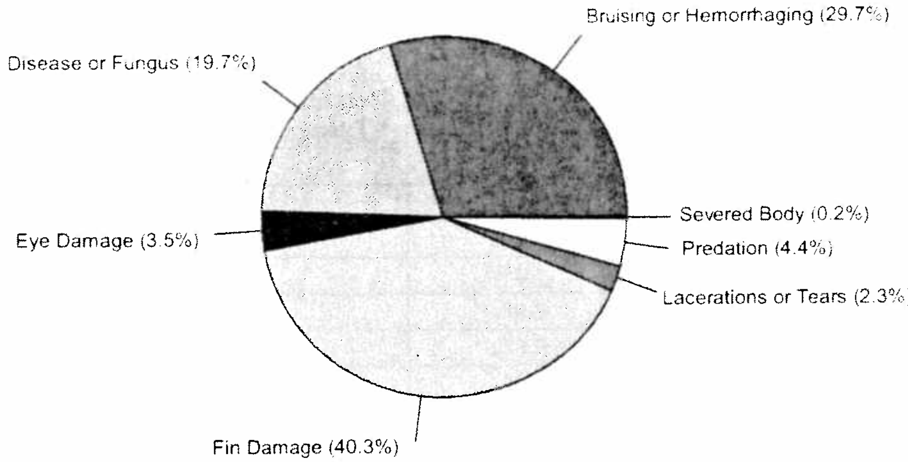

Figure 3-2
Distribution of Injury Types

For two of the species evaluated (bluegill and fathead minnow), there was a substantial amount of injury resulting from predation that occurred while fish were held in pens during the LIM assessment (Table 3-6). To investigate the possibility that predation was influencing the outcome of the injury regression analysis, a second regression was completed that eliminated fish with predation-related injuries. In the case of fathead minnow, eliminating predation injury did not affect the outcome of the model. In the case of bluegill, with the elimination of predation injury, the overall velocity treatment statistic was significant (P=0.0077), with the 0.30 m/s (1 ft/s) treatment exhibiting significantly greater mortality than the control (P=0.0034) (Table 3-7). It is unclear why bluegill exhibit greater mortality at 0.30 m/s (1 ft/s) than at 0.61 m/s (2 ft/s) or 0.91 m/s (3 ft/sec). Therefore, further research would be required if determining the underlying mechanism that leads to greater bluegill injury at lower velocities is considered important.

Table 3-6
Number of Predation Related Injuries by Species

Species	Predation
bigmouth buffalo	0
bluegill	48
channel catfish	2
fathead minnow	11
freshwater drum	1
golden shiner	0
largemouth bass	1
white sucker	0
yellow perch	3

Table 3-7
Summary of Pertinent P-Values from the Maximum Likelihood Estimates for the Injury Regression Models for All Species Tested

Species	Model	Length	Velocity	0.30 m/s	0.61 m/s	0.91 m/s
Bigmouth Buffalo	0.0225[a]	0.0040[a] ↓	0.2683	—	—	—
Bluegill	<0.0001[a]	<0.0001[a] ↓	0.1392	—	—	—
Bluegill (excluding predation)	0.0011[a]	0.0067[a] ↓	0.0077[a]	0.0034[a] +	0.3942	0.6589
Channel Catfish	0.0202[a]	0.0699	0.0294[a]	0.0097[a] +	0.9714	0.7655
Freshwater Drum	0.0002[a]	<0.0001[a] ↓	0.9959	—	—	—
Fathead Minnow	0.0114[a]	0.1924	0.0150[a]	0.0088[a] +	0.3043	0.5823
Fathead Minnow (excluding predation)	0.0037[a]	0.0962	0.0085[a]	0.0034[a] +	0.3294	0.8100
Golden Shiner	0.5768	—	—	—	—	—
Hybrid Bass	0.9929	—	—	—	—	—
Largemouth Bass	0.0003[a]	0.2244	0.0002[a]	0.2762	0.0009[a] +	0.0471[a] +
White Sucker	<0.0001[a]	<0.0001[a] ↓	0.5949	—	—	—
Yellow Perch	0.1659	—	—	—	—	—

[a] Significant at α 0.05
↓ Injury decreased with increasing fish length
+ = Significantly greater treatment than control injury

For bigmouth buffalo, injury rates among the velocity and control treatments ranged from 1.0% in the control and 0.61 m/s (2 ft/s) treatments to 3.5% in the 0.91 m/s (3 ft/s) treatment (Table 3-5). No significant differences among velocity treatments or controls were observed (P=0.2683; Table 3-7). Longer fish had lower injury rates (P=0.0040; Table 3-7).

With bluegill, injury rates among the velocity and control treatments ranged from 4.4% at 0.91 m/s (3 ft/s) to 7.3% at 0.61 m/s (2 ft/s) (Table 3-5). There were no significant differences among velocity and control treatments (P=0.1392; Table 3-7). Longer fish had lower injury rates (P<0.0001; Table 3-7). Eliminating the predation injured fish had the largest effect on the control and the 0.61 m/s (2 ft/s) treatment. Removing predation-related injury reduced overall control fish injury rates from 4.8% to 1.6% and for the 0.61 m/s (2 ft/s) treatment from 7.3% to 4.4% (Table 3-5). With the elimination of predation-related injury, velocity was a significant predictor of injury (P=0.0077; Table 3-7). Each of the velocity treatments had significantly greater mortality than the control (P<0.05). Longer fish had lower injury rates (P=0.0067; Table 3-7).

With channel catfish, injury rates among the velocity treatments ranged from 0% in 0.61 m/s (2 ft/s) treatment to 3.4% in the 0.30 m/s (1 ft/s) treatment (Table 3-5). Velocity was a significant predictor of injury (P=0.0294; Table 3-7). The 0.30 m/s (1 ft/s) treatment had significantly more injuries than the control (P=0.0097; Table 3-7). While not significant at an alpha level of 0.05, there was marginal evidence that larger fish experienced fewer injuries (P=0.0699; Table 3-7).

With freshwater drum, injury rates among the velocity and control treatments ranged from 0% in 0.30 m/s (1 ft/s) and 0.91 m/s (3 ft/s) treatments to 1.0% in the control (Table 3-5). There were no significant differences among velocity treatments (P=0.9954; Table 3-7). Longer fish may have had fewer injuries (P<0.0001; Table 3-7), but with the injury rates so low, this conclusion has little biological significance.

For fathead minnow, injury rates among the velocity and control treatments ranged from 13.9% in the 0.91 m/s (3 ft/s) treatment to 22.4% in the 0.30 m/s (1 ft/s) treatment (Table 3-5). The 0.30 m/s (1 ft/s) velocity treatment had significantly more injuries than the control (P=0.0088; Table 3-7). Removing fish with predation-related injury for the analysis, the injury rates among the velocity treatments ranged from 13.8% in the 0.91 m/s (3 ft/s) treatment to 22.4% in the 0.30 m/s (1 ft/s) treatment (Table 3-5). The 0.30 m/s (1 ft/s) velocity treatment had significantly more injuries than the control (P=0.0034; Table 3-7). This conclusion is not different from those observed when predation-related injury was included in the analysis.

Among golden shiner, injury rates ranged from 2.6% in 0.91 m/s (3 ft/s) treatment to 4.6% in the 0.61 m/s (2 ft/s) treatment (Table 3-5). There were too few injuries with this species for a meaningful logistic regression (P=0.5768; Table 3-7).

Hybrid striped bass injury rates were very low and ranged from 0.0% in the 0.30 m/s (1 ft/s) and 0.61 m/s (2 ft/s) and the control treatments to 0.3% in the 0.91 m/s (3 ft/s) treatment (Table 3-5). (P=0.9929; Table 3-7).

With largemouth bass, injury rates among the velocity treatments ranged from 0.8% in the 0.30 m/s (1 ft/s) treatment to 6.1% in the 0.61 m/s (2 ft/s) treatment (Table 3-5). The 0.61 m/s (2 ft/s) velocity treatment (P=0.0009; Table 3-7) and the 0.91 m/s (3 ft/s) treatment (P=0.0471; Table 3-7) had significantly greater injury rates than the control.

White sucker injury rates were high. Injury rates among the velocity and control treatments ranged from 20% in the control to 28.7% in the 0.30 m/s (1 ft/s) treatment (Table 3-5). Differences in injury rates among treatments were not significant (P=0.5949; Table 3-7). Longer fish had a lower injury rate (P<0.0001; Table 3-7).

Yellow perch injury rates were low. Among the velocity and control treatments, the injury rates ranged from 0.0% in 0.91 m/s (3 ft/s) treatment to 1.9% in the 0.61 m/s (2 ft/s) treatment (Table 3-5). The logisitic regression model for yellow perch injury was not significant (P=0.1659; Table 3-7).

Scale Loss

While occurring at a low rate for most species, the effect of velocity on scale loss showed a more consistent pattern across species than did injury or mortality. Most species exhibited an increase in scale loss at higher velocities and a decrease in scale loss with increasing fish length. Greater than 90% of the freshwater drum, hybrid striped bass, largemouth bass, and yellow perch had scale loss of 3% or less at all three velocities (Table 3-8). Golden shiner and bigmouth buffalo exhibited the greatest amount of scale loss (Table 3-8). Velocity was a significant predictor of scale loss for bigmouth buffalo, bluegill, freshwater drum, fathead minnow, golden shiner, white sucker, but not for hybrid striped bass, largemouth bass, or yellow perch. Four of the six species that exhibited significant effects of velocity on scale loss showed significantly greater velocity effects at 0.61 m/s (2 ft/s) and 0.91 m/s (3 ft/s), but not at 0.30 m/s (1 ft/s) (bigmouth buffalo, bluegill, freshwater drum, and white sucker). Only one species (golden shiner) exhibited significant scale loss at all three treatment velocities compared to the control. Surprisingly, fathead minnow showed significantly more scale loss at 0.30 m/s (1 ft/s), but not at 0.61 m/s (2 ft/s) or 0.91 m/s (3 ft/s). Length was a significant factor in predicting scale loss for five of the six species with reliable logistic regressions (bigmouth buffalo, bluegill, freshwater drum, golden shiner, white sucker, but not fathead minnow).

Bigmouth buffalo showed relatively high levels of scale loss with more than 12% of the fish experiencing scale loss of 20% or greater in each treatment (Table 3-8). For bigmouth buffalo, as velocity increased there was a pattern of greater scale loss. The 0.30 m/s (1 ft/s) treatment is not significantly different from the control, but the 0.61 m/s (2 ft/s) and the 0.91 m/s (3 ft/s) treatments were significantly greater than the control (Table 3-9). The coefficient for length was positive and significant ($P<0.0001$; Table 3-9) which indicates that larger fish tended to have less scale loss.

Bluegill showed little scale loss. Under each condition, greater than 82% of fish tested had scale loss of 3% or less (Table 3-9). For bluegill, as velocity increased, there was a pattern of greater scale loss. The 0.30 m/s (1 ft/s) treatment was not significantly different from the control, but the 0.61 m/s (2 ft/s) and the 0.91 m/s (3 ft/s) treatments were significantly greater than the control (Table 3-9). The coefficient for length was positive and significant ($P<0.0001$; Table 3-9) which suggests that larger fish tended to have less scale loss.

Freshwater drum showed very little scale loss. Less than 5% of fish under any treatment condition showed scale loss levels greater than 3% (Table 3-8). As velocity increased, there was a pattern of greater scale loss. The 0.30 m/s (1 ft/s) treatment was not significantly different from the control, but the 0.61 m/s (2 ft/s) and the 0.91 m/s (3 ft/s) treatments were (Table 3-9). The coefficient for length was positive and significant ($P<0.0001$; Table 3-9), which suggests that larger fish tended to have less scale loss.

Table 3-8
Frequency (%) of Scale Loss Category by Velocity and Species

Species	Scale Loss	Velocity			
		0.30 m/s	0.61 m/s	0.91 m/s	Control
Bigmouth Buffalo	<3%	42.0	16.0	29.6	48.5
	3–20%	45.3	58.5	21.1	38.0
	20–40%	9.4	18.1	15.5	10.2
	>40%	3.3	7.5	33.8	3.4
Bluegill	<3%	88.8	84.8	82.3	91.7
	3–20%	8.5	7.9	7.6	2.5
	20–40%	1.5	2.7	6.9	2.8
	>40%	1.2	4.6	3.2	3.0
Freshwater Drum	<3%	99.6	95.7	96.1	99.4
	3–20%	0.4	3.9	3.9	0.4
	20–40%	0.0	0.0	0.0	0.0
	>40%	0.0	0.4	0.0	0.2
Fathead Minnow	<3%	76.6	84.8	85.1	86.4
	3–20%	19.3	12.2	11.5	10.1
	20–40%	3.8	2.0	3.4	1.6
	>40%	0.3	0.9	0.0	1.8
Golden Shiner	<3%	24.7	23.0	15.9	48.3
	3–20%	40.0	38.5	31.1	40.4
	20–40%	27.1	23.3	28.0	9.5
	>40%	8.2	15.2	24.9	1.9
Hybrid Striped Bass	<3%	97.9	99.2	96.9	98.2
	3–20%	2.1	0.8	2.8	1.6
	20–40%	0.0	0.0	0.3	0.2
	>40%	0.0	0.0	0.0	0.0
Largemouth Bass	<3%	99.0	99.2	97.5	98.6
	3–20%	0.5	0.8	1.1	1.2
	20–40%	0.5	0.0	0.8	0.2
	>40%	0.0	0.0	0.6	0.0
White Sucker	<3%	72.9	59.3	48.9	81.3
	3–20%	17.2	20.7	25.4	13.3
	20–40%	7.5	15.0	20.1	3.5
	>40%	2.4	5.0	5.6	2.0
Yellow Perch	<3%	100.0	98.1	98.2	99.8
	3–20%	0.0	0.0	0.6	0.2
	20–40%	0.0	1.9	1.2	0.0
	>40%	0.0	0.0	0.0	0.0

Table 3-9
Summary of Pertinent P-Values from the Maximum Likelihood Estimates for the Scale Loss Regression Models for All Species Tested

Species	Model	Length	Velocity	0.30 m/s	0.61 m/s	0.91 m/s
Bigmouth Buffalo	<0.0001[a]	<0.0001[a] ↓	<0.0001[a]	0.2783	<0.0001[a] +	<0.0001[a] +
Bluegill	<0.0001[a]	<0.0001[a] ↓	0.0001[a]	0.1338	0.0004[a] +	<0.0001[a] +
Freshwater Drum	<0.0001[a]	<0.0001[a] ↓	0.0012[a]	0.7322	0.0013[a] +	0.0021[a] +
Fathead Minnow	0.0030[a]	0.7829	0.0011[a]	0.0003[a] +	0.5454	0.6294
Golden Shiner	<0.0001[a]	<0.0001[a] ↓	<0.0001[a]	<0.0001[a] +	<0.0001[a] +	<0.0001[a] +
Hybrid Bass	0.3758	—	—	—	—	—
Largemouth Bass	0.3131	—	—	—	—	—
White Sucker	<0.0001[a]	<0.0001[a] ↓	<0.0001[a]	0.4865	<0.0001 +	<0.0001 +
Yellow Perch	0.0753	—	—	—	—	—

[a] Significant at α 0.05
↓ Scale loss decreased with increasing fish length
+ = Significantly greater scale loss than control

Fathead minnow exhibited a moderate level of scale loss. More than 15% of fish under all treatment condition exhibited scale loss greater than 3% (Table 3-8). However, under no condition were more than 4.1% of fish categorized with scale loss greater than 20% (Table 3-8). Unexpectedly, the 0.30 m/s (1 ft/s) treatment had significantly more scale loss than the control (Table 3-8). The 0.61 m/s (2 ft/s) and 0.91 m/s (3 ft/s) treatments had more scale loss than the control, but not significantly more (Table 3-9). The coefficient for length was not significant (Table 3-9).

Golden shiner had fairly high levels of scale loss. Under all velocity treatment conditions, greater than 75% of fish exhibited scale loss greater than 3% (Table 3-8). However, more than half of the control fish had scale loss levels greater than 3%, indicating that much of the scale loss can be attributed to handling rather than encountering the screen (Table 3-8). For golden shiner, as velocity increased there was a pattern of greater scale loss. The odds ratio for all three velocity treatments vs. the control was well below 1.0 (P<0.0001; Table 3-9) and became progressively smaller as velocity increased indicating a strong velocity effect. The coefficient for length was positive and significant (P<0.0001; Table 3-9), which suggests that larger fish tended to have less scale loss.

Hybrid striped bass exhibited very little scale loss. Under all conditions, more than 96% of fish, were categorized with the lowest level of scale loss (<3%) (Table 3-8). There was too little scale loss for a meaningful logistic regression (Table 3-9).

Largemouth bass exhibited very little scale loss. Fish tested at 0.91 m/s (3 ft/s) had the highest scale loss, but it was still very low. Less than 3% of fish tested at 0.91 m/s (3 ft/s) exhibited scale loss greater than 3% (Table 3-8). For largemouth bass, distribution of scale loss across velocity treatments remained fairly constant. There were no significant velocity or length effects (Table 3-9).

White sucker exhibited moderate scale loss. Scale loss increased with increasing velocity. The percentage of fish with scale loss greater than 3% increased from 27% to 41% to 51% at 0.30, 0.61, and 0.91 m/s, respectively (1, 2, and 3 ft/s, respectively) (Table 3-8). Roughly 20% of the control fish exhibited scale loss greater than 3% indicating that a substantial portion of velocity treatment fish with higher levels of scale loss could have been a result of handling rather than encountering the screen. The 0.30 m/s (1 ft/s) treatment was not significantly different from the control, but the 0.61 m/s (2 ft/s) and the 0.91 m/s (3 ft/s) treatments were (Table 3-9). The coefficient for length was positive and significant (P<0.0001; Table 3-9) which indicates that larger fish tended to have less scale loss.

For yellow perch, there was very little scale loss. Under no condition did more than 1.3% of fish exhibited scale loss greater than 3% (Table 3-8). In fact, there was too little scale loss for meaningful regression analysis (P=0.0753; Table 3-9).

Comparison of Laboratory to Field Results

This laboratory evaluation of modified traveling screens has shown survival high enough to demonstrate that such screens have the potential to meet the Phase II §316(b) impingement mortality reduction standard (80-95%: EPA 2004). Intuitively, one might expect that organisms tested in the laboratory would have higher survival than those observed in the field. Organisms collected in the field are often exposed to site-specific factors that impact physiological condition and potentially reduce survival (e.g., disease, extremes in water temperature, debris loading, poor water quality, inter- and intra-specific competition for resources, etc.). Laboratory studies, on the other hand, are conducted under conditions where the effect of natural stressors, particularly disease organisms, is typically more controlled. Therefore, it is not necessarily surprising that high survival was observed in this laboratory study. The observed survival rates were consistently high and at the high end of the range observed in previous field screen studies. Therefore, it was deemed important to review past data in light of these results to ensure that the high survival rates were not an artifact of the laboratory experimental protocol.

Previous data included in the review were primarily from studies that:

- were conducted at facilities with modified Ristroph or dual-flow screens
- were conducted at facilities with the more sophisticated bucket designs developed in the 1980s
- had similar species to those tested in the laboratory[6]

Since the methods used in the field studies to evaluate survival (e.g., duration of impingement, spraywash pressures, collection techniques, holding protocols, duration of holding, season, water temperatures, etc.) and the level of detail included in the reports varied, it was not possible to calculate mean survival rates for each species. Instead, the median reported value is presented in Table 3-10. In cases when more than one estimate was generated for a facility during different times of year, each value was included separately.

In most cases, data were limited to the same genus as those tested in the laboratory. There were two exceptions: *Ameiurus* sp. was included in the analysis of Ictaluridae (catfishes); until recently these two genera were considered to be the same. *Notropis* sp. (shiner) was included with *Notemigonus* sp. (shiner).

Table 3-10
Comparison of EPRI Laboratory Results to those Observed in Previous Pilot- and Full-Scale Field Evaluations[1]

	Ictaluridae (Catfish)		Freshwater Drum		Lepomis sp. (Sunfishes)		Micropterus Sp. (Bass)		Morone Sp.		Notemigonus Sp. + Notropis Sp. (Shiners)		Perca Sp. (Perches)		Pimephales Sp. (Minnows)	
	Field	Lab	Field	Lab	Field	Lab	Field	Lab	Field	Lab	Field	Lab	Field	Lab	Field	Lab
Median Survival	72.0	99.6	100.0	100.0	97.5	97.8	83.4	97.8	91.0	99.7	90.8	98.5	100.0	98.8	100.0	97.7
Minimum Survival	33.3	99.0	100.0	99.5	54.0	95.4	66.7	97.2	34.5	99.6	42.9	98.4	98.9	97.4	100.0	96.8
Maximum Survival	84.1	100.0	100.0	100.0	100.0	99.1	100.0	99.0	100.0	100.0	99.7	98.7	100.0	99.2	100.0	98.3
Number of Estimates	5	3	1	3	9	3	2	3	35	3	21	3	3	3	1	3

[1] Data were used from the following studies: Normandeau 1995 (Roseton); Beak Consultants 2000a (Dunkirk), Beak Consultants 2000b (Huntley); Fletcher 1990 (Indian Point); Consolidated Edison 1996 (Arthur Kill); PSE&G 1999 (Salem); PSEG 2004 (Salem)

In general, there was a greater range of reported values from the field than from the laboratory. The median survival from the field tended to be lower than was observed in the laboratory. In cases where median survival from the field was greater than those observed in the laboratory, the higher field value was probably an artifact of a small number of test organisms or data from few studies. Surprisingly, in-field survival of catfish (channel catfish, brown bullhead, and white catfish), which are often considered "hardy," was substantially lower than what was observed in the laboratory (72.0% vs. 99.6%) (Table 3-10). With this exception, the survival rates achieved in the field are close to or exceed those observed in the laboratory, indicating that the survival observed in the laboratory are not outside the bounds of what can be achieved in the field.

Duration of Impingement (DI) Tests

This study investigated the impact of longer durations of impingement (DI) on mortality, injury, and scale loss. Results indicate that increasing DI tends to increase mortality, injury, and scale loss. Statistical analysis tables for these tests are included in Appendix B.

Survival was variable by species, but was relatively high for all species. Mortality rates for all species never exceeded 10% under any condition. There were no mortalities observed for channel catfish with any of the DI treatment conditions (Table 3-11). Fathead minnow exhibited an nonintuitive pattern of mortality. Mortality was lowest, 0.7%, in the controls which does conform to expectation, but mortality was intermediate for 10 min and highest for the 6 min (6.4%) and 8 min (6.7%) treatments (Table 3-11). The analysis shows that the full model is not significant (P=0.1244; Table B-5). With golden shiner, mortality increased with DI, if the control treatment is eliminated. However, the mortality response for the controls was about midway in the gradient across durations. Even with this anomaly, the analysis shows that mortality significantly increased with increasing DI (P=0.0038; Table B-11). Length had a significant negative effect on mortality (P=0.0001; Table A-11), indicating that larger fish experienced less mortality.

Table 3-11
Mortality and Injury Rates by Species and Duration of Impingement Test

Species		Duration of Impingement					
		2	4	6	8	10	Control
Channel Catfish	Mortality	—	—	0.0	0.0	0.0	0.8
	Injury	—	—	0.0	0.0	0.0	0.0
Fathead Minnow	Mortality	—	—	6.4	6.7	2.9	0.7
	Injury	—	—	8.5	3.3	2.9	1.3
Golden Shiner	Mortality	0.0	0.0	3.8	15.1	12.7	9.3
	Injury	0.0	0.0	5.0	6.9	9.9	9.3

Patterns in injury between species were inconclusive. Since no injuries were observed for channel catfish it was not necessary to conduct any statistical analysis. Fathead minnow and golden shiner showed different responses. Injury rates for fathead minnow followed the same non-intuitive pattern that was observed for mortality (i.e., injury was highest at an intermediate value – 6 min [8.5%]) (Table 3-11). The analysis shows that the full model is not significant (P=0.3688; Table B-7).

Golden shiner mortality among the controls showed unusually high mortality (9.3%; Table 3-11). Excluding the controls, the injury rate followed an increasing trend with duration. The logistic regression showed a positive coefficient for DI, but this was not statistically significant (*P*=0.1464; Table B-13). If the controls are excluded, the coefficient increases from 0.0878 to 0.2483, but this is only marginally significant (*P*=0.0948; Table B-14). Longer fish showed a decreased likelihood of injury (*P*=0.0050; Table B-13).

Fathead minnow experienced relatively low levels of scale loss, with 80% or greater having 3% or less scale loss under all conditions. For fathead minnow, there was a significant increase in scale loss with increasing DI (*P*=0.0319; Table B-9). Smaller fish had less scale loss than larger fish, which is counter to what was observed with other species, but this relationship was not significant (*P*=0.7066; Table B-9). Note that duration and length are confounded to some degree in this data set, because the control fish, on average, were smaller than the treatment fish.

Among golden shiner, there was substantial observed scale loss even among control fish (Table 3-12). More than half the fish in each of the DI tests exhibited the highest level of scale loss (>40%). For golden shiner, scale loss increased with increasing duration of impingement (*P*<0.0001; Table B-16). There was also a reduction in scale loss as golden shiner increased in length (*P*=0.0144; Table B-16).

Table 3-12
Frequency (%) of Scale Loss Categories by Species and Duration of Impingement

Species	Scale Loss Category	Duration of Impingement					
		2	4	6	8	10	Control
Fathead Minnow	1			95.7	80.0	94.3	98.7
	2			0.0	10.0	2.9	1.3
	3			0.0	6.7	0.0	0.0
	4			4.3	3.3	2.9	0.0
Golden Shiner	1	0.0	0.0	3.8	2.7	14.1	42.9
	2	28.6	11.1	8.8	9.6	12.7	41.9
	3	14.3	33.3	16.3	15.1	12.7	7.6
	4	57.1	55.6	71.3	72.6	60.6	7.6

4
CONCLUSIONS

The primary conclusions of this study are as follows:

- Post-impingement survival was high for all species and velocities tested (>95%) indicating that modified traveling screens are likely to meet the Phase II §316(b) Rule for impingement mortality reduction for these species. Higher rates of injury and scale loss were observed at 0.61 m/s (2 ft/s) and 0.91 m/s (3 ft/s) than at 0.30 m/s (1 ft/s), indicating that the survival potential of fish with this screen technology may be highest at velocities less than 0.61 m/s (2 ft/s).
- Fish length played an important role in survival, injury, and scale loss. There is a trend toward increasing survival and decreasing injury and scale loss as fish grow larger. In all cases where fish length was a significant factor, the pattern of greater survival or less injury and scale loss as fish increased in length was observed. Thus, even though survival of all sized fish was high, modified traveling screens offer a higher level of protection to larger which are more valuable.
- Despite a general trend toward greater survival at lower velocities, velocity was only a significant factor in survival for bluegill. This lack of correlation to velocity indicates that modified screens can likely be used at facilities with approach velocities greater than 0.30 m/s (1 ft/s). Velocities greater than 0.30 m/s (1 ft/s), however, can create more turbulence in the fish lifting buckets, which may impart more scale loss.
- Injury rates were highly variable by species indicating that overall observed survival rates in the field will be determined largely on the species composition and abundance at the individual CWIS.
- It is not unreasonable to assume that site-specific environmental factors (e.g., debris, water quality, water temperature, turbulence, etc.) will impact fish physiology and potentially increase post-impingement mortality, injury, and scale loss at field sites using modified screens. However, a comparison of these laboratory results with results observed in the field indicate that the excellent survival observed in the laboratory is within the bounds of what has been observed in the field with similar screen designs.
- Underwater video recordings and visual observations during testing revealed that the majority of fish encountered the modified traveling screen without "impinging" in the traditional sense. Most fish followed one of three paths to the bucket: 1) they impinged briefly on the screen mesh and wiggles across the screen surface to the bucket while the screen basket was still submerged, 2) they tail tapped against the screen mesh until being scooped into the bucket near the water surface, or 3) sought refuge in the relative hydraulic calm of the bucket without touching the screen face.

- Longer durations of impingement may result in higher mortality, injury, and scale loss, especially at durations of impingement greater than 6 min. However, given the water depth in most CWIS, there may be considerable leeway in developing an operations protocol that would not require continuous rotation, but would still meet the impingement mortality reduction standard.
- Studies to further improve the hydraulic conditions within the fish buckets at higher velocities could further reduce the injury and scale loss increases which were observed at 0.61 m/s (2 ft/s) and 0.91 m/s (3 ft/s).

These studies provide additional information to support the use of modified traveling screens to meet the Phase II § 316(b) IM performance standard.

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A

STATISTICAL ANALYSIS TABLES – VELOCITY TESTS

Species-specific results of the logistic regressions are presented in the following sections. For each species, the first table gives the raw frequencies and summary statistics by velocity treatment and the second table gives a summary of logistic regression results. The first table for each species shows the frequency of live, dead (or injured, not injured), and total recovered for each velocity, as well as percent dead or injured and mean length. The second table for each species summarizes various estimates obtained from the logistic regression analyses. The first row shows the intercept of the model, which is generally not of interest but was given for completeness. The second, third, and fourth rows give estimates of the difference in logits between mortality or injury in the treatment conditions 0.30 m/s (1 ft/s), 0.61 m/s (2 ft/s), and 0.91 m/s (3 ft/s), respectively, and the control. Row 5 reports the cumulative chi-square for all velocity treatments. Row 6 gives the coefficient of the covariate Fork Length and row 7 reports the cumulative chi-square for the full model (velocity treatments and Fork Length). In some cases, there was too little mortality or too few injuries for a successful logistic regress (i.e., the model failed to converge on a reliable estimate).

The model results for each species (second table in each section) are hierarchical. To interpret the significance of each component of the model (p-value), start by looking at the full model (last row in each table). If the p-value for the full model was >0.05 then the model failed to converge on a reliable estimate and the Fork Length and Velocity components of the model were not significant regardless of their p-value. By contrast, if the p-value of the full model was significant ($P<0.05$), then the model converged upon a reliable estimate and it is appropriate to look at the velocity and fork length components individually. Fork Length was or was not significant depending on the p-value; p-values <0.05 were significant. When p-values for Velocity were >0.05, then velocity was not significant and individual comparisons of velocity treatments to the control were not valid regardless of their p-value. If the p-value of the Velocity component of the model was significant ($P<0.05$), then it is appropriate to look at the individual comparisons of velocity treatments to the controls. When individual velocity comparisons to the control had p-values greater than 0.05, then they were not significant. When p-values were <0.05, then the comparison was statistically significant. Negative estimates in Column 3 (Estimate) indicate that there was a decrease in mortality or injury, and positive estimates indicate there was an increase in mortality or injury.

The second scale loss tables are slightly different from those for injury and mortality. A positive coefficient of the estimate value means the probability in the lower levels of scale loss increase while a negative coefficient means the probability of lower levels of scale loss decreases and thus probability in the higher categories increases.

Because these are cumulative probabilities, the intercept terms start negative and get progressively larger indicating increasing probability. Cumulative probability moving toward levels of greater scale loss must increase, because each cumulative probability includes the probability of the level of scale loss below.

Bigmouth Buffalo

Table A-1
Summary of Live, Dead, and Mean Length by Velocity Treatment for Bigmouth Buffalo

	Velocity				Total
	0.3 m/s	0.6 m/s	0.9 m/s	Control	
Dead	0	0	0	1	1
Live	245	94	142	294	775
Percent Dead	0.00	0.00	0.00	0.34	
Total	245	94	142	295	776
Mean Length (mm)	71.85	72.34	72.35	72.08	

Table A-2
Analysis of Maximum Likelihood Estimates for the Survival Regression Model for Bigmouth Buffalo

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept	1	1.6169	5.60	0.08	.	0.7729
0.3 m/s vs Con	1	-9.7025	148.90	0.00	0.00	0.9480
0.6 m/s vs Con	1	-9.6272	243.15	0.00	0.00	0.9684
0.9 m/s vs Con	1	-9.6711	193.84	0.00	0.00	0.9602
Velocity Effects	3	.	.	0.01	.	0.9998
Fork Length	1	-0.1070	0.09	1.51	0.90	0.2191
Full Model	4	.	.	1.52	.	0.8233

Table A-3
Summary of Injury Rate and Mean Length by Velocity Treatment for Bigmouth Buffalo

	Velocity				Total
	0.3 m/s	0.6 m/s	0.9 m/s	Control	
Injured	4	1	5	3	13
Not Injured	241	93	137	292	763
Percent Injured	1.63	1.06	3.52	1.02	.
Total	245	94	142	295	776
Mean Length	71.85	72.34	72.35	72.08	.

Table A-4
Analysis of Maximum Likelihood Estimates for the Injury Regression Model for Bigmouth Buffalo

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept	1	2.4940	2.39	1.09	.	0.2958
0.3 m/s vs Con	1	0.5780	0.78	0.55	1.78	0.4598
0.6 m/s vs Con	1	0.2320	1.18	0.04	1.26	0.8435
0.9 m/s vs Con	1	1.3971	0.75	3.44	4.04	0.0637
Velocity Effects	3	.	.	3.94	.	0.2683
Fork Length	1	-0.1031	0.04	8.30	0.90	0.0040
Full Model	4	.	.	11.39	.	0.0225

Table A-5
Summary of Frequencies of Scale Loss Categories and Mean Length by Velocity Treatment for Bigmouth Buffalo

Scale Loss		Velocity				Total
		0.3 m/s	0.6 m/s	0.9 m/s	Control	
1	Frequency	103	15	42	143	303
	Percent	42.04	15.96	29.58	48.47	.
2	Frequency	111	55	30	112	308
	Percent	45.31	58.51	21.13	37.97	.
3	Frequency	23	17	22	30	92
	Percent	9.39	18.09	15.49	10.17	.
4	Frequency	8	7	48	10	73
	Percent	3.27	7.45	33.80	3.39	.
Total	Frequency	245	94	142	295	776
Mean Length		71.85	72.34	72.35	72.08	

Table A-6
Analysis of Maximum Likelihood Estimates for the Scale Loss Regression Model for Bigmouth Buffalo

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept 1	1	-3.5704	0.71	25.64	.	<0.0001
Intercept 2	1	-1.6325	0.70	5.50	.	0.0190
Intercept 3	1	-0.5722	0.70	0.67	.	0.4120
0.3 m/s vs. Con	1	-0.1784	0.16	1.18	0.84	0.2783
0.6 m/s vs. Con	1	-1.1166	0.22	25.09	0.33	<0.0001
0.9 m/s vs. Con	1	-1.7086	0.20	74.67	0.18	<0.0001
Velocity Effects	3	.	.	89.80	.	<0.0001
Fork Length	1	0.0488	0.01	25.54	1.05	<0.0001
Full Model	4	.	.	108.06	.	<0.0001

Bluegill

Table A-7
Summary of Live, Dead, and Mean Length by Velocity Treatment for Bluegill

	Velocity				Total
	0.3 m/s	0.6 m/s	0.9 m/s	Control	
Dead	3	15	7	6	31
Live	337	313	310	391	1,351
Percent Dead	0.88	4.57	2.21	1.51	.
Total	340	328	317	397	1,382
Mean Length (mm)	47.01	47.27	46.96	45.74	.

Table A-8
Analysis of Maximum Likelihood Estimates for the Survival Regression Model for Bluegill

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept	1	6.9443	1.65	17.72	.	<0.0001
0.3 m/s vs Con	1	-0.1062	0.74	0.02	0.90	0.8860
0.6 m/s vs Con	1	2.0153	0.57	12.55	7.50	0.0004
0.9 m/s vs Con	1	1.1757	0.63	3.54	3.24	0.0601
Velocity Effects	3	.	.	17.70	.	0.0005
Fork Length	1	-0.2728	0.04	39.11	0.76	<0.0001
Full Model	4	.	.	43.88	.	<0.0001

Table A-9
Summary of Injury Rate and Mean Length by Velocity Treatment for Bluegill

	Velocity				Total
	0.3 m/s	0.6 m/s	0.9 m/s	Control	
Injured	23	24	14	19	80
Not Injured	317	304	303	378	1,302
Percent Injured	6.76	7.32	4.42	4.79	.
Total	340	328	317	397	1,382
Mean Length	47.01	47.27	46.96	45.74	.

Table A-10
Analysis of Maximum Likelihood Estimates for the Injury Regression Model for Bluegill

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept	1	1.5870	0.96	2.71	.	0.0995
0.3 m/s vs Con	1	0.5043	0.32	2.41	1.66	0.1204
0.6 m/s vs Con	1	0.6403	0.32	3.91	1.90	0.0481
0.9 m/s vs Con	1	0.0668	0.37	0.03	1.07	0.8551
Velocity Effects	3	.	.	5.49	.	0.1392
Fork Length	1	-0.1044	0.02	22.20	0.90	<0.0001
Full Model	4	.	.	25.80	.	<0.0001

Table A-11
Summary of Injury Rate and Mean Length by Velocity Treatment for Bluegill Excluding Predation Injury

	Velocity				Total
	0.3 m/s	0.6 m/s	0.9 m/s	Control	
Injured	23	14	13	6	56
Not Injured	317	304	303	378	1,302
Percent Injured	6.76	4.40	4.11	1.56	.
Total	340	318	316	384	1,358
Mean Length	47.01	47.41	46.98	45.96	.

Table A-12
Analysis of Maximum Likelihood Estimates for the Injury Regression Model for Bluegill Excluding Predation Injury

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept	1	-1.1059	1.17	0.90	.	0.3430
0.3 m/s vs Con	1	1.5913	0.47	11.63	4.91	0.0006
0.6 m/s vs Con	1	1.1674	0.50	5.52	3.21	0.0188
0.9 m/s vs Con	1	1.0681	0.50	4.53	2.91	0.0332
Velocity Effects	3	.	.	11.91	.	0.0077
Fork Length	1	-0.0680	0.03	7.34	0.93	0.0067
Full Model	4	.	.	18.35	.	0.0011

Table A-13
Summary of Frequencies of Scale Loss Categories and Mean Length by Velocity Treatment for Bluegill

Scale Loss		Velocity				Total
		0.3 m/s	0.6 m/s	0.9 m/s	Control	
1	Frequency	302	278	261	364	1,205
	Percent	88.82	84.76	82.33	91.69	.
2	Frequency	29	26	24	10	89
	Percent	8.53	7.93	7.57	2.52	.
3	Frequency	5	9	22	11	47
	Percent	1.47	2.74	6.94	2.77	.
4	Frequency	4	15	10	12	41
	Percent	1.18	4.57	3.15	3.02	.
Total	Frequency	340	328	317	397	1,382
Mean Length		47.01	47.27	46.96	45.74	

Table A-14
Analysis of Maximum Likelihood Estimates for the Scale Loss Regression Model for Bluegill

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept 1	1	-1.7708	0.69	6.53	.	0.0106
Intercept 2	1	-0.9764	0.69	1.98	.	0.1597
Intercept 3	1	-0.1596	0.70	0.05	.	0.8202
0.3 m/s vs. Con	1	-0.3814	0.25	2.25	0.68	0.1338
0.6 m/s vs. Con	1	-0.8550	0.24	12.65	0.43	0.0004
0.9 m/s vs. Con	1	-0.9796	0.24	17.12	0.38	<0.0001
Velocity Effects	3	.	.	21.19	.	0.0001
Fork Length	1	0.0938	0.02	35.95	1.10	<0.0001
Full Model	4	.	.	50.06	.	<0.0001

Channel Catfish

Table A-15
Summary of Live, Dead, and Mean Length by Velocity Treatment for Channel Catfish

	Velocity				Total
	0.3 m/s	0.6 m/s	0.9 m/s	Control	
Dead	2	0	1	0	3
Live	204	148	245	490	1,087
Percent Dead	0.97	0.00	0.41	0.00	.
Total	206	148	246	490	1,090
Mean Length (mm)	63.53	62.46	63.81	63.13	.

Table A-16
Analysis of Maximum Likelihood Estimates for the Survival Regression Model for Channel Catfish

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept	1	-7.9326	121.52	0.00	.	0.9480
0.3 m/s vs Con	1	11.2827	121.41	0.01	79435.08	0.9260
0.6 m/s vs Con	1	-0.0559	249.68	0.00	0.95	0.9998
0.9 m/s vs Con	1	10.4145	121.41	0.01	33338.53	0.9316
Velocity Effects	3	.	.	0.51	.	0.9173
Fork Length	1	-0.1312	0.09	2.06	0.88	0.1508
Full Model	4	.	.	2.56	.	0.6336

Table A-17
Summary of Injury Rate and Mean Length by Velocity Treatment for Channel Catfish

	Velocity				Total
	0.3 m/s	0.6 m/s	0.9 m/s	Control	
Injured	7	0	1	3	11
Not Injured	199	148	245	487	1,079
Percent Injured	3.40	0.00	0.41	0.61	.
Total	206	148	246	490	1,090
Mean Length	63.53	62.46	63.81	63.13	.

Table A-18
Analysis of Maximum Likelihood Estimates for the Injury Regression Model for Channel Catfish

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept	1	-0.0133	2.77	0.00	.	0.9962
0.3 m/s vs Con	1	1.8068	0.70	6.68	6.09	0.0097
0.6 m/s vs Con	1	-11.5136	321.34	0.00	0.00	0.9714
0.9 m/s vs Con	1	-0.3458	1.16	0.09	0.71	0.7655
Velocity Effects	3	.	.	8.99	.	0.0295
Fork Length	1	-0.0831	0.05	3.29	0.92	0.0699
Full Model	4	.	.	11.65	.	0.0202

Freshwater Drum

Table A-19
Summary of Live, Dead, and Mean Length by Velocity Treatment for Freshwater Drum

	Velocity				Total
	0.3 m/s	0.6 m/s	0.9 m/s	Control	
Dead	0	0	1	1	2
Live	243	230	203	511	1,187
Percent Dead	0.00	0.00	0.49	0.20	.
Total	243	230	204	512	1,189
Mean Length (mm)	84.60	84.49	84.95	84.67	.

Table A-20
Analysis of Maximum Likelihood Estimates for the Survival Regression Model for Freshwater Drum

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept	1	6.4441	4.35	2.19	.	0.1386
0.3 m/s vs Con	1	-10.3575	257.77	0.00	0.00	0.9679
0.6 m/s vs Con	1	-10.8099	246.42	0.00	0.00	0.9650
0.9 m/s vs Con	1	1.9176	1.72	1.24	6.80	0.2658
Velocity Effects	3	.	.	1.24	.	0.7429
Fork Length	1	-0.1731	0.07	6.06	0.84	0.0138
Full Model	4	.	.	6.12	.	0.1903

Table A-21
Summary of Injury Rate and Mean Length by Velocity Treatment for Freshwater Drum

	Velocity				Total
	0.3 m/s	0.6 m/s	0.9 m/s	Control	
Injured	0	2	0	5	7
Not Injured	243	228	204	507	1,182
Percent Injured	0.00	0.87	0.00	0.98	.
Total	243	230	204	512	1,189
Mean Length	84.60	84.49	84.95	84.67	.

Table A-22
Analysis of Maximum Likelihood Estimates for the Injury Regression Model for Freshwater Drum

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept	1	6.7508	2.20	9.39	.	0.0022
0.3 m/s vs Con	1	-11.8074	221.64	0.00	0.00	0.9575
0.6 m/s vs Con	1	-0.2255	0.94	0.06	0.80	0.8098
0.9 m/s vs Con	1	-11.4589	285.35	0.00	0.00	0.9680
Velocity Effects	3	.	.	0.06	.	0.9959
Fork Length	1	-0.1496	0.03	21.67	0.86	<0.0001
Full Model	4	.	.	21.68	.	0.0002

Table A-23
Summary of Frequencies of Scale Loss Categories and Mean Length by Velocity Treatment for Freshwater Drum

Scale Loss		Velocity				Total
		0.3 m/s	0.6 m/s	0.9 m/s	Control	
1	Frequency	242	220	196	509	1,167
	Percent	99.59	95.65	96.08	99.41	.
2	Frequency	1	9	8	2	20
	Percent	0.41	3.91	3.92	0.39	.
4	Frequency	0	1	0	1	2
	Percent	0.00	0.43	0.00	0.20	.
Total	Frequency	243	230	204	512	1,189
Mean Length		84.60	84.49	84.95	84.67	

Table A-24
Analysis of Maximum Likelihood Estimates for the Scale Loss Regression Model for Freshwater Drum

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept 1	1	-2.1849	1.59	1.88	.	0.1706
Intercept 2	1	0.3209	1.70	0.04	.	0.8503
0.3 m/s vs. Con	1	0.3965	1.16	0.12	1.49	0.7322
0.6 m/s vs. Con	1	-2.1394	0.66	10.40	0.12	0.0013
0.9 m/s vs. Con	1	-2.1191	0.69	9.45	0.12	0.0021
Velocity Effects	3	.	.	15.86	.	0.0012
Fork Length	1	0.0914	0.02	20.38	1.10	<0.0001
Full Model	4	.	.	31.67	.	<0.0001

Fathead Minnow

Table A-25
Summary of Live, Dead, and Mean Length by Velocity Treatment for Fathead Minnow

	Velocity				Total
	0.3 m/s	0.6 m/s	0.9 m/s	Control	
Dead	9	11	5	6	31
Live	384	332	291	487	1,494
Percent Dead	2.29	3.21	1.69	1.22	.
Total	393	343	296	493	1,525
Mean Length (mm)	56.38	56.22	55.83	54.14	.

Table A-26
Analysis of Maximum Likelihood Estimates for the Survival Regression Model for Fathead Minnow

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept	1	-2.1728	1.67	1.69	.	0.1933
0.3 m/s vs Con	1	0.7557	0.54	1.95	2.13	0.1622
0.6 m/s vs Con	1	1.0930	0.52	4.41	2.98	0.0358
0.9 m/s vs Con	1	0.4206	0.62	0.47	1.52	0.4943
Velocity Effects	3	.	.	4.79	.	0.1876
Fork Length	1	-0.0419	0.03	1.81	0.96	0.1783
Full Model	4	.	.	5.80	.	0.2147

Table A-27
Summary of Injury Rate and Mean Length by Velocity Treatment for Fathead Minnow

	Velocity				Total
	0.3 m/s	0.6 m/s	0.9 m/s	Control	
Injured	88	62	41	74	265
Not Injured	305	281	255	419	1,260
Percent Injured	22.39	18.08	13.85	15.01	.
Total	393	343	296	493	1,525
Mean Length	56.38	56.22	55.83	54.14	.

Table A-28
Analysis of Maximum Likelihood Estimates for the Injury Regression Model for Fathead Minnow

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept	1	-2.4897	0.60	17.44	.	0.0000
0.3 m/s vs Con	1	0.4616	0.18	6.87	1.59	0.0088
0.6 m/s vs Con	1	0.1950	0.19	1.06	1.22	0.3043
0.9 m/s vs Con	1	-0.1161	0.21	0.30	0.89	0.5823
Velocity Effects	3	.	.	10.46	.	0.0150
Fork Length	1	0.0139	0.01	1.70	1.01	0.1924
Full Model	4	.	.	12.98	.	0.0114

Table A-29
Summary of Injury Rate and Mean Length by Velocity Treatment for Fathead Minnow Excluding Predation Injury

	Velocity				Total
	0.3 m/s	0.6 m/s	0.9 m/s	Control	
Injured	88	58	41	69	256
Not Injured	305	281	255	419	1,260
Percent Injured	22.39	17.11	13.85	14.14	.
Total	393	339	296	488	1,516
Mean Length	56.38	56.27	55.83	54.18	.

Table A-30
Analysis of Maximum Likelihood Estimates for the Injury Regression Model for Fathead Minnow Excluding Predation Injury

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept	1	-2.7854	0.61	21.00	.	<0.0001
0.3 m/s vs Con	1	0.5245	0.18	8.60	1.69	0.0034
0.6 m/s vs Con	1	0.1905	0.20	0.95	1.21	0.3294
0.9 m/s vs Con	1	-0.0513	0.21	0.06	0.95	0.8100
Velocity Effects	3	.	.	11.69	.	0.0085
Fork Length	1	0.0180	0.01	2.77	1.02	0.0962
Full Model	4	.	.	15.52	.	0.0037

Table A-31
Summary of Frequencies of Scale Loss Categories and Mean Length by Velocity Treatment for Fathead Minnow

Scale Loss		Velocity				Total
		0.3 m/s	0.6 m/s	0.9 m/s	Control	
1	Frequency	301	291	252	426	1,270
	Percent	76.59	84.84	85.14	86.41	.
2	Frequency	76	42	34	50	202
	Percent	19.34	12.24	11.49	10.14	.
3	Frequency	15	7	10	8	40
	Percent	3.82	2.04	3.38	1.62	.
4	Frequency	1	3	0	9	13
	Percent	0.25	0.87	0.00	1.83	.
Total	Frequency	393	343	296	493	1,525
Mean Length		56.38	56.22	55.83	54.14	

Table A-32
Analysis of Maximum Likelihood Estimates for the Scale Loss Regression Model for Fathead Minnow

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept 1	1	1.6749	0.61	7.60	.	0.0058
Intercept 2	1	3.4052	0.62	30.18	.	<0.0001
Intercept 3	1	4.8381	0.67	52.91	.	<0.0001
0.3 m/s vs. Con	1	-0.6443	0.18	13.02	0.53	0.0003
0.6 m/s vs. Con	1	-0.1213	0.20	0.37	0.89	0.5454
0.9 m/s vs. Con	1	-0.1012	0.21	0.23	0.90	0.6294
Velocity Effects	3	.	.	16.01	.	0.0011
Fork Length	1	0.0030	0.01	0.08	1.00	0.7829
Full Model	4	.	.	16.03	.	0.0030

Golden Shiner

Table A-33
Summary of Live, Dead, and Mean Length by Velocity Treatment for Golden Shiner

	Velocity				Total
	0.3 m/s	0.6 m/s	0.9 m/s	Control	
Dead	6	5	6	6	23
Live	359	369	383	479	1,590
Percent Dead	1.64	1.34	1.54	1.24	.
Total	365	374	389	485	1,613
Mean Length (mm)	75.19	73.36	73.69	73.13	.

Table A-34
Analysis of Maximum Likelihood Estimates for the Survival Regression Model for Golden Shiner

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept	1	1.2373	1.15	1.16	.	0.2815
0.3 m/s vs Con	1	0.6216	0.60	1.08	1.86	0.2990
0.6 m/s vs Con	1	0.2818	0.62	0.20	1.33	0.6507
0.9 m/s vs Con	1	0.5513	0.60	0.84	1.74	0.3596
Velocity Effects	3	.	.	1.32	.	0.7242
Fork Length	1	-0.0876	0.02	21.07	0.92	<0.0001
Full Model	4	.	.	21.26	.	0.0003

Table A-35
Summary of Injury Rate and Mean Length by Velocity Treatment for Golden Shiner

	Velocity				Total
	0.3 m/s	0.6 m/s	0.9 m/s	Control	
Injured	10	17	10	18	55
Not Injured	355	357	379	467	1,558
Percent Injured	2.74	4.55	2.57	3.71	.
Total	365	374	389	485	1,613
Mean Length	75.19	73.36	73.69	73.13	.

Table A-36
Analysis of Maximum Likelihood Estimates for the Injury Regression Model for Golden Shiner

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept	1	-3.1714	0.77	16.78	.	<0.0001
0.3 m/s vs Con	1	-0.3112	0.40	0.60	0.73	0.4380
0.6 m/s vs Con	1	0.2117	0.35	0.38	1.24	0.5399
0.9 m/s vs Con	1	-0.3783	0.40	0.89	0.69	0.3448
Velocity Effects	3	.	.	2.86	.	0.4141
Fork Length	1	-0.0012	0.01	0.01	1.00	0.9087
Full Model	4	.	.	2.89	.	0.5768

Table A-37
Summary of Frequencies of Scale Loss Categories and Mean Length by Velocity Treatment for Golden Shiner

Scale Loss		Velocity				Total
		0.3 m/s	0.6 m/s	0.9 m/s	Control	
1	Frequency	90	86	62	234	472
	Percent	24.66	22.99	15.94	48.25	.
2	Frequency	146	144	121	196	607
	Percent	40.00	38.50	31.11	40.41	.
3	Frequency	99	87	109	46	341
	Percent	27.12	23.26	28.02	9.48	.
4	Frequency	30	57	97	9	193
	Percent	8.22	15.24	24.94	1.86	.
Total	Frequency	365	374	389	485	1,613
Mean Length		75.19	73.36	73.69	73.13	

Table A-38
Analysis of Maximum Likelihood Estimates for the Scale Loss Regression Model for Golden Shiner

Row Label	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept 1	1	-2.1518	0.27	63.72	.	<0.0001
Intercept 2	1	-0.3207	0.26	1.47	.	0.2252
Intercept 3	1	1.1099	0.27	17.28	.	<0.0001
0.3 m/s vs. Con	1	-1.1969	0.13	81.71	0.30	<0.0001
0.6 m/s vs. Con	1	-1.3252	0.13	101.23	0.27	<0.0001
0.9 m/s vs. Con	1	-1.9675	0.13	215.66	0.14	<0.0001
Velocity Effects	3	.	.	226.75	.	<0.0001
Fork Length	1	0.0293	0.00	70.32	1.03	<0.0001
Full Model	4	.	.	274.29	.	<0.0001

Hybrid Striped Bass

Table A-39
Summary of Live, Dead, and Mean Length by Velocity Treatment for Hybrid Striped Bass

	Velocity				Total
	0.3 m/s	0.6 m/s	0.9 m/s	Control	
Dead	1	0	1	0	2
Live	242	241	355	498	1,336
Percent Dead	0.41	0.00	0.28	0.00	.
Total	243	241	356	498	1,338
Mean Length (mm)	60.54	60.59	60.31	60.88	.

Table A-40
Analysis of Maximum Likelihood Estimates for the Survival Regression Model for Hybrid Striped Bass

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept	1	-19.3077	167.89	0.01	.	0.9084
0.3 m/s vs Con	1	10.9720	167.75	0.00	58223.71	0.9478
0.6 m/s vs Con	1	0.0130	293.80	0.00	1.01	1.0000
0.9 m/s vs Con	1	10.6148	167.75	0.00	40735.18	0.9495
Velocity Effects	3	.	.	0.07	.	0.9952
Fork Length	1	0.0463	0.11	0.17	1.05	0.6758
Full Model	4	.	.	0.26	.	0.9921

Table A-41
Summary of Injury Rate and Mean Length by Velocity Treatment for Hybrid Striped Bass

	Velocity				Total
	0.3 m/s	0.6 m/s	0.9 m/s	Control	
Injured	0	0	1	0	1
Not Injured	243	241	355	498	1,337
Percent Injured	0.00	0.00	0.28	0.00	.
Total	243	241	356	498	1,338
Mean Length	60.54	60.59	60.31	60.88	.

Table A-42
Analysis of Maximum Likelihood Estimates for the Injury Regression Model for Hybrid Striped Bass

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept	1	-8.2805	127.49	0.00	.	0.9482
0.3 m/s vs Con	1	-0.3006	239.76	0.00	0.74	0.9990
0.6 m/s vs Con	1	-0.2988	239.60	0.00	0.74	0.9990
0.9 m/s vs Con	1	9.9702	126.57	0.01	21380.07	0.9372
Velocity Effects	3	.	.	0.01	.	0.9997
Fork Length	1	-0.1280	0.26	0.24	0.88	0.6265
Full Model	4	.	.	0.25	.	0.9929

Table A-43
Summary of Frequencies of Scale Loss Categories and Mean Length by Velocity Treatment for Hybrid Striped Bass

Scale Loss		Velocity				Total
		0.3 m/s	0.6 m/s	0.9 m/s	Control	
1	Frequency	238	239	345	489	1,311
	Percent	97.94	99.17	96.91	98.19	.
2	Frequency	5	2	10	8	25
	Percent	2.06	0.83	2.81	1.61	.
3	Frequency	0	0	1	1	2
	Percent	0.00	0.00	0.28	0.20	.
Total	Frequency	243	241	356	498	1,338
Mean Length		60.54	60.59	60.31	60.88	

Table A-44
Analysis of Maximum Likelihood Estimates for the Scale Loss Regression Model for Hybrid Striped Bass

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept 1	1	2.0212	2.48	0.66	.	0.4157
Intercept 2	1	4.6462	2.57	3.26	.	0.0711
0.3 m/s vs. Con	1	-0.1169	0.56	0.04	0.89	0.8358
0.6 m/s vs. Con	1	0.7997	0.79	1.03	2.22	0.3090
0.9 m/s vs. Con	1	-0.5333	0.46	1.37	0.59	0.2415
Velocity Effects	3	.	.	3.54	.	0.3160
Fork Length	1	0.0326	0.04	0.64	1.03	0.4254
Full Model	4	.	.	4.23	.	0.3758

Largemouth Bass

Table A-45
Summary of Live, Dead, and Mean Length by Velocity Treatment for Largemouth Bass

	Velocity				Total
	0.3 m/s	0.6 m/s	0.9 m/s	Control	
Dead	4	8	10	4	26
Live	390	351	351	497	1,589
Percent Dead	1.02	2.23	2.77	0.80	.
Total	394	359	361	501	1,615
Mean Length (mm)	99.38	98.44	97.32	98.59	.

Table A-46
Analysis of Maximum Likelihood Estimates for the Survival Regression Model for Largemouth Bass

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept	1	-1.4944	1.91	0.61	.	0.4349
0.3 m/s vs Con	1	0.2519	0.71	0.13	1.29	0.7231
0.6 m/s vs Con	1	1.0269	0.62	2.77	2.79	0.0960
0.9 m/s vs Con	1	1.2290	0.60	4.25	3.42	0.0393
Velocity Effects	3	.	.	5.89	.	0.1170
Fork Length	1	-0.0345	0.02	3.12	0.97	0.0773
Full Model	4	.	.	9.26	.	0.0549

Table A-47
Summary of Injury Rate and Mean Length by Velocity Treatment for Largemouth Bass

	Velocity				Total
	0.3 m/s	0.6 m/s	0.9 m/s	Control	
Injured	3	22	14	8	47
Not Injured	391	337	347	493	1,568
Percent Injured	0.76	6.13	3.88	1.60	.
Total	394	359	361	501	1,615
Mean Length	99.38	98.44	97.32	98.59	.

Table A-48
Analysis of Maximum Likelihood Estimates for the Injury Regression Model for Largemouth Bass

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept	1	-2.5116	1.36	3.41	.	0.0647
0.3 m/s vs Con	1	-0.7410	0.68	1.19	0.48	0.2762
0.6 m/s vs Con	1	1.3882	0.42	10.97	4.01	0.0009
0.9 m/s vs Con	1	0.8917	0.45	3.94	2.44	0.0471
Velocity Effects	3	.	.	19.21	.	0.0002
Fork Length	1	-0.0165	0.01	1.48	0.98	0.2244
Full Model	4	.	.	20.85	.	0.0003

Table A-49
Summary of Frequencies of Scale Loss Categories and Mean Length by Velocity Treatment for Largemouth Bass

Scale Loss		Velocity				Total
		0.3 m/s	0.6 m/s	0.9 m/s	Control	
1	Frequency	390	356	352	494	1,592
	Percent	98.98	99.16	97.51	98.60	.
2	Frequency	2	3	4	6	15
	Percent	0.51	0.84	1.11	1.20	.
3	Frequency	2	0	3	1	6
	Percent	0.51	0.00	0.83	0.20	.
4	Frequency	0	0	2	0	2
	Percent	0.00	0.00	0.55	0.00	.
Total	Frequency	394	359	361	501	1,615
Mean Length		99.38	98.44	97.32	98.59	

Table A-50
Analysis of Maximum Likelihood Estimates for the Scale Loss Regression Model for Largemouth Bass

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept 1	1	2.6850	1.91	1.97	.	0.1607
Intercept 2	1	3.7523	1.94	3.76	.	0.0525
Intercept 3	1	5.1439	2.03	6.42	.	0.0113
0.3 m/s vs. Con	1	0.3118	0.63	0.24	1.37	0.6211
0.6 m/s vs. Con	1	0.5258	0.69	0.57	1.69	0.4492
0.9 m/s vs. Con	1	-0.5802	0.51	1.30	0.56	0.2544
Velocity Effects	3	.	.	3.93	.	0.2692
Fork Length	1	0.0161	0.02	0.69	1.02	0.4058
Full Model	4	.	.	4.76	.	0.3131

White Sucker

Table A-51
Summary of Live, Dead, and Mean Length by Velocity Treatment for White Sucker

	Velocity				Total
	0.3 m/s	0.6 m/s	0.9 m/s	Control	
Dead	16	16	17	14	63
Live	357	323	357	445	1,482
Percent Dead	4.29	4.72	4.55	3.05	.
Total	373	339	374	459	1,545
Mean Length (mm)	76.20	79.39	80.41	82.63	.

Table A-52
Analysis of Maximum Likelihood Estimates for the Survival Regression Model for White Sucker

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept	1	0.5821	0.77	0.57	.	0.4510
0.3 m/s vs Con	1	0.0113	0.38	0.00	1.01	0.9763
0.6 m/s vs Con	1	0.2740	0.38	0.52	1.32	0.4695
0.9 m/s vs Con	1	0.3151	0.37	0.72	1.37	0.3968
Velocity Effects	3	.	.	1.24	.	0.7423
Fork Length	1	-0.0516	0.01	27.89	0.95	<0.0001
Full Model	4	.	.	29.62	.	<0.0001

Table A-53
Summary of Injury Rate and Mean Length by Velocity Treatment for White Sucker

	Velocity				Total
	0.3 m/s	0.6 m/s	0.9 m/s	Control	
Injured	107	86	84	92	369
Not Injured	266	253	290	367	1,176
Percent Injured	28.69	25.37	22.46	20.04	.
Total	373	339	374	459	1,545
Mean Length	76.20	79.39	80.41	82.63	.

Table A-54
Analysis of Maximum Likelihood Estimates for the Injury Regression Model for White Sucker

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept	1	2.1408	0.38	31.40	.	<0.0001
0.3 m/s vs Con	1	0.2091	0.17	1.50	1.23	0.2212
0.6 m/s vs Con	1	0.1704	0.18	0.93	1.19	0.3355
0.9 m/s vs Con	1	0.0555	0.18	0.10	1.06	0.7514
Velocity Effects	3	.	.	1.89	.	0.5949
Fork Length	1	-0.0438	0.00	89.81	0.96	<0.0001
Full Model	4	.	.	97.94	.	<0.0001

Table A-55
Summary of Frequencies of Scale Loss Categories and Mean Length by Velocity Treatment for White Sucker

Scale Loss		Velocity				Total
		0.3 m/s	0.6 m/s	0.9 m/s	Control	
1	Frequency	272	201	183	373	1,029
	Percent	72.92	59.29	48.93	81.26	.
2	Frequency	64	70	95	61	290
	Percent	17.16	20.65	25.40	13.29	.
3	Frequency	28	51	75	16	170
	Percent	7.51	15.04	20.05	3.49	.
4	Frequency	9	17	21	9	56
	Percent	2.41	5.01	5.61	1.96	.
Total	Frequency	373	339	374	459	1,545
Mean Length		76.20	79.39	80.41	82.63	

Table A-56
Analysis of Maximum Likelihood Estimates for the Scale Loss Regression Model for White Sucker

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept 1	1	-3.1549	0.36	77.90	.	<0.0001
Intercept 2	1	-1.8870	0.35	28.94	.	<0.0001
Intercept 3	1	-0.2506	0.36	0.48	.	0.4882
0.3 m/s vs. Con	1	-0.1215	0.17	0.48	0.9	0.4865
0.6 m/s vs. Con	1	-1.0766	0.17	41.89	0.34	<0.0001
0.9 m/s vs. Con	1	-1.5568	0.16	94.14	0.21	<0.0001
Velocity Effects	3	.	.	130.76	.	<0.0001
Fork Length	1	0.0580	0.00	177.33	1.06	<0.0001
Full Model	4	.	.	265.31	.	<0.0001

Yellow Perch

Table A-57
Summary of Live, Dead, and Mean Length by Velocity Treatment for Yellow Perch

	Velocity				Total
	0.3 m/s	0.6 m/s	0.9 m/s	Control	
Dead	1	4	2	5	12
Live	119	152	160	493	924
Percent Dead	0.83	2.56	1.23	1.00	.
Total	120	156	162	498	936
Mean Length (mm)	50.91	50.22	52.70	48.19	.

Table A-58
Analysis of Maximum Likelihood Estimates for the Survival Regression Model for Yellow Perch

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept	1	2.4870	2.42	1.05	.	0.3049
0.3 m/s vs Con	1	0.1907	1.11	0.03	1.21	0.8641
0.6 m/s vs Con	1	1.2686	0.69	3.34	3.56	0.0674
0.9 m/s vs Con	1	0.7535	0.86	0.76	2.12	0.3826
Velocity Effects	3	.	.	3.55	.	0.3143
Fork Length	1	-0.1581	0.06	7.81	0.85	0.0052
Full Model	4	.	.	10.07	.	0.0392

Table A-59
Summary of Injury Rate and Mean Length by Velocity Treatment for Yellow Perch

	Velocity				Total
	0.3 m/s	0.6 m/s	0.9 m/s	Control	
Injured	2	3	0	5	10
Not Injured	118	153	162	493	926
Percent Injured	1.67	1.92	0.00	1.00	.
Total	120	156	162	498	936
Mean Length	50.91	50.22	52.70	48.19	.

Table A-60
Analysis of Maximum Likelihood Estimates for the Injury Regression Model for Yellow Perch

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept	1	1.9616	2.65	0.55	.	0.4588
0.3 m/s vs Con	1	0.8651	0.86	1.00	2.38	0.3162
0.6 m/s vs Con	1	0.9431	0.75	1.58	2.57	0.2093
0.9 m/s vs Con	1	-11.1567	264.45	0.00	0.00	0.9663
Velocity Effects	3	.	.	1.95	.	0.5837
Fork Length	1	-0.1457	0.06	5.62	0.86	0.0178
Full Model	4	.	.	6.48	.	0.1659

Table A-61
Summary of Frequencies of Scale Loss Categories and Mean Length by Velocity Treatment for Yellow Perch

Scale Loss		Velocity				Total
		0.3 m/s	0.6 m/s	0.9 m/s	Control	
1	Frequency	120	153	159	497	929
	Percent	100.00	98.08	98.15	99.80	.
2	Frequency	0	0	1	1	2
	Percent	0.00	0.00	0.62	0.20	.
4	Frequency	0	3	2	0	5
	Percent	0.00	1.92	1.23	0.00	.
Total	Frequency	120	156	162	498	936
Mean Length		50.91	50.22	52.70	48.19	

Table A-62
Analysis of Maximum Likelihood Estimates for the Scale Loss Regression Model for Yellow Perch

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept 1	1	-0.0116	3.10	0.00	.	0.9970
Intercept 2	1	0.3321	3.11	0.01	.	0.9149
0.3 m/s vs. Con	1	9.0834	225.29	0.00	8807.50	0.9678
0.6 m/s vs. Con	1	-2.5644	1.17	4.81	0.08	0.0284
0.9 m/s vs. Con	1	-2.7416	1.18	5.38	0.06	0.0204
Velocity Effects	3	.	.	5.85	.	0.1192
Fork Length	1	0.1381	0.07	4.01	1.15	0.0451
Full Model	4	.	.	8.49	.	0.0753

B

STATISTICAL ANALYSIS TABLES – DURATION OF IMPINGEMENT TESTS

Channel Catfish

Table B-1
Summary of Live, Dead and Mean Length by Duration of Impingement for Channel Catfish

	Duration						Total
	Control	2 min	4 min	6 min	8 min	10 min	
Dead	1	.	.	0	0	0	1
Live	119	.	.	115	108	103	445
Percent Dead	0.83	.	.	0.00	0.00	0.00	.
Total	120	.	.	115	108	103	446
Mean Length	66.43	.	.	65.10	64.35	64.59	.

Table B-2
Analysis of Maximum Likelihood Estimates for the Regression Model for the Duration of Impingement of Channel Catfish

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept	1	-5.8418	11.36	0.26	.	0.6072
Duration	1	-1.6227	21.56	0.01	0.20	0.9400
Fork Length	1	0.0159	0.17	0.01	1.02	0.9249
Full Model	2	.	.	0.01	.	0.9927

Table B-3
Summary of Injury Rates and Mean Length by Duration of Impingement for Channel Catfish

	Duration						Total
	Control	2 min	4 min	6 min	8 min	10 min	
Injured	0	.	.	0	0	0	0
Not Injured	120	.	.	115	108	103	446
Percent Injured	0.00	.	.	0.00	0.00	0.00	.
Total	120	.	.	115	108	103	446
Mean Length	66.42	.	.	65.10	64.35	64.59	.

Fathead Minnow

Table B-4
Summary of Live, Dead and Mean Length by Duration of Impingement for Fathead Minnow

	Duration						Total
	Control	2 min	4 min	6 min	8 min	10 min	
Dead	1	.	.	3	2	1	7
Live	149	.	.	44	28	34	255
Percent Dead	0.67	.	.	6.38	6.67	2.86	.
Total	150	.	.	47	30	35	262
Mean Length	45.49	.	.	52.49	53.27	53.69	.

Table B-5
Analysis of Maximum Likelihood Estimates for the Regression Model of Duration of Impingement of Fathead Minnow – Survival

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept	1	-1.2324	3.80	0.11	.	0.7454
Duration	1	0.2449	0.12	4.00	1.28	0.0456
Fork Length	1	-0.0718	0.08	0.73	0.93	0.3930
Full Model	2	.	.	4.17	.	0.1244

Table B-6
Summary of Injury Rates and Mean Length by Duration of Impingement for Fathead Minnow

	Duration						Total
	Control	2 min	4 min	6 min	8 min	10 min	
Injured	2	.	.	4	1	1	8
Not Injured	148	.	.	43	29	34	254
Percent Injured	1.33	.	.	8.51	3.33	2.86	.
Total	150	.	.	47	30	35	262
Mean Length	45.49	.	.	52.49	53.27	53.69	.

Table B-7
Analysis of Maximum Likelihood Estimates for the Regression Model of Duration of Impingement for Fathead Minnow – Injury

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept	1	-5.4635	3.08	3.15	.	0.0760
Duration	1	0.0886	0.10	0.72	1.09	0.3950
Fork Length	1	0.0326	0.06	0.25	1.03	0.6139
Full Model	2	.	.	2.00	.	0.3688

Table B-8
Summary of Frequencies of Scale Loss Categories and Mean Length by Duration of Impingement for Fathead Minnow

Scale Loss Category		Duration						Total
		Control	2 min	4 min	6 min	8 min	10 min	
1	Frequency	148	.	.	45	24	33	250
	Percent	98.67	.	.	95.74	80.00	94.29	
2	Frequency	2	.	.	0	3	1	6
	Percent	1.33	.	.	0.00	10.00	2.86	
3	Frequency	0	.	.	0	2	0	2
	Percent	0.00	.	.	0.00	6.67	0.00	
4	Frequency	0	.	.	2	1	1	4
	Percent	0.00	.	.	4.26	3.33	2.86	
Total	Frequency	150	.	.	47	30	35	262
	Mean length	45.49	.	.	52.49	53.27	53.69	

Table B-9
Analysis of Maximum Likelihood Estimates for the Regression Model of for Fathead Minnow – Scale Loss

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept 1	1	5.0876	2.69	3.57	.	0.0588
Intercept 2	1	5.8217	2.71	4.62	.	0.0317
Intercept 3	1	6.2414	2.73	5.24	.	0.0220
Duration	1	-0.1991	0.09	4.60	0.82	0.0319
Fork Length	1	-0.0211	0.06	0.14	0.98	0.7066
Full Model	2	.	.	7.23	.	0.0270

Golden Shiner

Table B-10
Summary of Live, Dead and Mean Length by Duration of Impingement for Golden Shiner

	Duration						Total
	Control	2 min	4 min	6 min	8 min	10 min	
Dead	10	0	0	3	11	9	33
Live	98	7	9	77	62	62	315
Percent Dead	9.26	0.00	0.00	3.75	15.07	12.68	.
Total	108	7	9	80	73	71	348
Mean Length	69.39	67.57	71.56	80.20	76.89	76.73	.

Table B-11
Analysis of Maximum Likelihood Estimates for the Regression Model for the Duration of Impingement of Golden Shiner – Survival

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept	1	0.7334	0.91	0.65	.	0.4185
Duration	1	0.1689	0.06	8.39	1.18	0.0038
Fork Length	1	-0.0579	0.01	16.07	0.94	0.0001
Full Model	2	.	.	18.18	.	0.0001

Table B-12
Summary of Injury Rates and Mean Length by Duration of Impingement for Golden Shiner

	Duration						Total
	Control	2 min	4 min	6 min	8 min	10 min	
Injured	10	0	0	4	5	7	26
Not Injured	98	7	9	76	68	64	322
Percent Injured	9.26	0.00	0.00	5.00	6.85	9.86	.
Total	108	7	9	80	73	71	348
Mean Length	69.39	67.57	71.56	80.20	76.89	76.73	.

Table B-13
Analysis of Maximum Likelihood Estimates for the Regression Model for Duration of Impingement of Golden Shiner – Injury

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept	1	-0.1208	0.98	0.02	.	0.9015
Duration	1	0.0878	0.06	2.11	1.09	0.1464
Fork Length	1	-0.0422	0.02	7.89	0.96	0.0050
Full Model	2	.	.	8.15	.	0.0170

Table B-14
Analysis of Maximum Likelihood Estimates for the Regression Model for Duration of Impingement of Golden Shiner Excluding Controls – Injury

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept	1	-0.5147	1.76	0.09	.	0.7698
Duration	1	0.2483	0.15	2.79	1.28	0.0948
Fork Length	1	-0.0562	0.02	7.99	0.95	0.0047
Full Model	2	.	.	9.83	.	0.0073

Table B-15
Summary of Frequencies of Scale Loss Categories and Mean Length by Duration of Impingement for Golden Shiner

Scale Loss Category		Duration						Total
		Control	2 min	4 min	6 min	8 min	10 min	
1	Frequency	45	0	0	3	2	10	60
	Percent	42.86	0.00	0.00	3.75	2.74	14.08	
2	Frequency	44	2	1	7	7	9	70
	Percent	41.90	28.57	11.11	8.75	9.59	12.68	
3	Frequency	8	1	3	13	11	9.00	45
	Percent	7.62	14.29	33.33	16.25	15.07	12.68	
4	Frequency	8	4	5	57	53	43.00	170
	Percent	7.62	57.14	55.56	71.25	72.60	60.56	
Total	Frequency	105	7	9	80	73	71	345
	Mean Length	69.39	67.57	71.56	80.20	76.89	76.73	

Table B-16
Analysis of Maximum Likelihood Estimates for the Regression Model of Scale Loss for Golden Shiner – Scale Loss

	DF	Estimate	Standard Error	Wald Chi-Square	Odds Ratio	p-Value
Intercept 1	1	-1.6711	0.54	9.70	.	0.0018
Intercept 2	1	-0.2405	0.53	0.21	.	0.6493
Intercept 3	1	0.5077	0.53	0.91	.	0.3392
Duration	1	-0.3307	0.03	103.41	0.72	<0.0001
Fork Length	1	0.0176	0.01	5.99	1.02	0.0144
Full Model	2	.	.	103.79	.	<0.0001

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