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Intake Diversion Dam Fish Screens

Evaluation of Fish Screens for Protecting Early Life Stages of Pallid Sturgeon (*Scaphirhynchus albus*)

U.S. Department of the Interior
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14. ABSTRACT
A laboratory study was conducted to evaluate the application of National Oceanic and Atmospheric Administration (NOAA) salmonid fry criteria for Pallid Sturgeon (*Scaphirhynchus albus*) 14 – 95 mm in total length. The study evaluated four related metrics: swimming endurance, impingement survival, screening effectiveness, and recovery of impinged fish from traveling fish screens. The study was conducted to provide information for the selection and design of fish screens for the Lower Yellowstone Irrigation District Main Canal fish screening project. The study was conducted at the Bureau of Reclamation's Water Resources Research Laboratory in Denver Colorado (Denver, CO) with hatchery spawned Pallid Sturgeon larvae provided from the U.S. Fish and Wildlife Service's Gavin's Point National Fish Hatchery (Yankton, SD). Results indicate sub-20 mm TL larvae displayed little retractile swimming ability, and easily passed through NOAA criteria fish screen material. Pallid Sturgeon 30 – 45 mm TL displayed poor swimming performance, but experimental results suggest mortality rates were unaffected by impingement on a fish screen for periods < 10 minutes (maximum impingement time evaluated) when fish were recovered by back flushing the screen. Fish larger than 45 mm TL displayed greater swimming ability, and were capable of swimming several minutes against a fish screen approach velocity of 12 cm/s. Though experimental sample sizes were small, study results suggest NOAA salmonid fry criteria may be appropriate to effectively prevent entrainment of Pallid Sturgeon > 45 mm TL. Results also showed plastic belt inclined traveling screens can be effective for recovery of impinged juvenile Pallid Sturgeon.

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The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Disclaimer

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Executive Summary

A laboratory study was conducted to evaluate the applicability of National Oceanic and Atmospheric Administration (NOAA) salmonid fry screening criteria for larval and juvenile Pallid Sturgeon (*Scaphirhynchus albus*) < 100 mm total length (TL). The study evaluated four related metrics: swimming endurance, impingement survival, screening effectiveness, and recovery of impinged fish from a traveling fish screen. The study was conducted to provide information for the design of fish screens for the Lower Yellowstone Irrigation District Main Canal fish screening project. All experiments were completed at the Bureau of Reclamation's Water Resources Research Laboratory (Denver, CO) using hatchery spawned Pallid Sturgeon provided by the U.S. Fish and Wildlife Service's Gavin's Point National Fish Hatchery (Yankton, SD). Sturgeon used during testing ranged from approximately 14 to 95 mm TL. Results indicate sub-20 mm TL larvae displayed little retractile swimming ability, and easily passed through NOAA criteria fish screen material. Pallid Sturgeon 30 – 45 mm TL displayed poor swimming performance, but experimental results suggest mortality rates were unaffected by impingement on a fish screen for periods up to 10 minutes. Fish larger than 45 mm TL displayed greater swimming ability, and were capable of swimming several minutes against a fish screen approach velocity of 12 cm/s. Though experimental sample sizes were small, study results suggest NOAA salmonid fry criteria may be appropriate to effectively prevent entrainment of Pallid Sturgeon > 45 mm TL. Screen impingement for periods ≤ 10 minutes (maximum impingement time evaluated) had no effect on 48-hour survival when fish were recovered by back flushing the screen. Results also showed plastic belt inclined traveling screens can be effective for recovery of impinged juvenile Pallid Sturgeon.

Introduction

Intake Diversion Dam and the diversion headworks for the Lower Yellowstone Irrigation District's Main Canal are located on the Yellowstone River, about 17 miles north east of Glendive, Montana. The effect of the dam and unscreened diversion on fish of the Lower Yellowstone River has been the subject of multiple studies by state and federal resource agencies. Fish population studies conducted by Montana Fish Wildlife and Parks (Backes and Gardner 1994; Stewart 1986, 1988, 1990, 1991) indicate the dam is a partial barrier to many species and likely a total barrier to some. Entrainment studies by Hiebert (2000) indicate significant numbers of fish are entrained with diversion flow into the canal. Pallid Sturgeon (*Scaphirhynchus albus*) were listed as a federally endangered species in 1990 by the U.S. Fish and Wildlife Service and are among many fish species native to the Yellowstone River system impacted by the diversion dam. Providing fish passage at the Intake Diversion Dam and protecting sturgeon from entrainment with irrigation diversion have been identified as important links in Pallid Sturgeon recovery. Fish passage at Intake Diversion Dam will open access to many miles of main stem and tributary habitat, providing long undisturbed stretches of free-flowing habitat critical in the recovery of larval sturgeon (Wildhaber 2007). Early life-stages of Pallid Sturgeon are of particular concern to local and regional biologists as newly hatched fish commonly drift with downstream currents, making them extremely susceptible to entrainment (Kynard 2002). This study investigated swimming performance, and screening of larval and juvenile pallid sturgeon following established National Oceanic and Atmospheric Administration (NOAA) criteria for screening salmonid fry (NOAA 1997).

Literature Review

Prior studies evaluating screening effectiveness for larval and juvenile Pallid Sturgeon were not identified in our review of the literature, and though studies describing the swimming performance of juvenile Pallid Sturgeon (> 90 mm fork length (FL)) have been reported, there is no published literature detailing the swimming performance of larval and young juvenile pallid sturgeon.

Understanding the swimming ability of fish subjected to screening facilities, as a function of life-stage, is important to fish screen design, as swimming ability ultimately determines water velocities fish can tolerate without encountering impingement or entrainment. Adams (1999) reported sustained swimming speeds (defined as the maximum velocity at which fish could maintain swimming for > 200 minutes) for juvenile Pallid Sturgeon at two size classes: 13.0 – 16.8 cm and 17.0 – 20.5 cm FL. Maximum sustained swim speeds for small and large size groups of sturgeon, subjected to temperatures between 17 – 20 °C, were 0.10 and 0.25 m/s, respectively. In the same study, Adams reported burst swim speeds (defined as the maximum velocity at which test fish could maintain swimming for < ~ 10 seconds) ranged from nearly 0.4 to 0.7 m/s for all sizes of fish tested. Kynard (COE 2002) employed the use of a circular flume to measure swim speed of both juvenile Pallid (45.6 cm mean FL) and Shovelnose Sturgeon

(*Scaphirhynchus platorynchus*, 39.2 cm mean FL), and reported juvenile Pallid Sturgeon were able to swim at speeds consistent to 0.9 – 2.0 body lengths per second for several hours. Hoover et al. (2005) also studied swim speeds of juvenile Pallid Sturgeon (9.1 and 13.3 cm mean FL) exposed to temperatures between 21 – 23 °C. They reported results similar to those of Adams (1999) and indicate maximum sustained swimming speeds of small and large size classes of fish tested were 0.20 and 0.35 m/s, respectively.

Experimental Design

This study was designed to obtain information needed to evaluate fish screening effectiveness for early life stages of Pallid Sturgeon. For the purposes of this study, Pallid Sturgeon < 30 mm total length (TL) are commonly referred to as larval fish and fish > 30 mm TL (and < 100 mm TL) are referred to as juvenile fish. Four related topics, and subsequent experimental designs, were identified as critical in the development of appropriate screening criteria for young Pallid Sturgeon:

1. Swimming endurance
2. Screen impingement survival
3. Screening effectiveness following NOAA salmonid fry criteria
4. Recovery of screen impinged fish

A summary of fish source and care, and the experimental design for each topic follows.

Fish Source and Care

Pallid Sturgeon were obtained from Gavin's Point National Fish Hatchery (NFH) located near Yankton, South Dakota between July and August 2007. All sturgeon were transported to the Bureau of Reclamation's (Reclamation) Water Resources Research Laboratory (Denver, CO). The first group of fish, consisting of approximately 9-day old pallid sturgeon (14 mm mean TL, 1 mm mean width), were transported to the laboratory on July 2, 2007, and a second group of 6-week-old (35 – 85 mm TL) sturgeon were transported to the laboratory in mid-August.

Pallid Sturgeon used in swimming endurance experiments were held in 375-liter, circular, flow through tanks, and provided continuous flows of water. Fish were provided continuous aeration to ensure dissolved oxygen levels were maintained > 8 mg/L. Fish were slowly acclimated from transport temperatures (1.5 °C/day) to 17°C, and holding temperatures remained within ± 1 °C throughout experimentation. Sturgeon were held for at least 7 days prior to swimming endurance experiments to allow acclimation to the new holding environment and recuperation from transport associated stress. Pallid Sturgeon used in experiments for screen impingement survival, screening effectives, and recovery of screen impinged fish were held in 38-liter aquariums and provided continuous flows of water equivalent in temperature to temperatures used in each test apparatus (see below). Fish were acclimated to the laboratory water for at least two days prior to initiating replicate testing.

All Pallid Sturgeon were provided satiation rations of dry crumbled pellet feed provided by the hatchery. In general, fish appeared to readily feed within 2 – 3 days upon arriving to the laboratory. However, holding mortality rates of larval sturgeon < 25 mm TL was typically high (> 50%), and appeared to be due to an inability or unwillingness of larval fish to initiate exogenous feeding. Gavin's Point National Fish Hatchery reported similar problems and elevated mortality rates with cohorts during the same period. The initiation of exogenous feeding for larval sturgeon typically occurs at about 10 days (Wildhaber 2007), and many researchers have identified the onset of feeding as a critical period for larval survival and development (Gisbert and Williot 1997; Deng et al. 2003; and Gisbert and Doroshov 2003). For all experiments, we ensured fish appeared healthy and were swimming in an appropriate manner prior to each replicate.

Swimming Endurance

Numerous research projects aimed at measuring the swimming performance of juvenile Pallid Sturgeon have been performed (see "Literature Review" above). However, there is limited knowledge as to the swimming ability of larval and early juvenile Pallid Sturgeon, life-stages of critical concern and commonly affected by the Intake Diversion Dam on the lower Yellowstone River. Developing swimming endurance curves, at all life stages and at varying water temperatures, for fish that encounter fish exclusion facilities, is critical when designing and developing operational criteria for such facilities. Swimming endurance curves provide the most comprehensive measure of performance for fish affected by exclusion facilities because they evaluate fish swimming performance at multiple ecologically relevant swimming speeds, from sustained to prolonged to burst speeds, and can be developed at varying water temperatures. This is important because a fishes swimming endurance is not only species dependent, but also dependent upon life stage of fish and water temperature at which the fish is being tested. Fish exclusion facility water velocities outside of the range of a fishes swimming endurance curve may ultimately entrain and impinge fish on screens, and negatively effect fish survival.

Between July and September of 2007, we employed the use of a fish swimming flume (Figure 1), designed and constructed by Reclamation personnel, to develop swimming endurance curves for multiple size classes of larval and early juvenile Pallid Sturgeon. The swimming flume was equipped with two removable, variable speed motors, a 1/40 hp motor capable of generating velocities between 0.0 and 0.3 m/s, in approximate 0.01 m/s intervals, and a 1/10 hp motor capable of generating velocities between 0.0 and 2.0 m/s, in approximate 0.05 m/s intervals.

To develop swimming endurance curves for Pallid Sturgeon we measured a range of swimming speeds (estimated to be between burst and sustained speeds) of multiple size classes of fish. This was done opportunistically, as a limited number of rapidly growing larval fish were available for testing. For each swimming performance replicate, test fish were removed from their appropriate holding tank, measured, transferred to the swimming chamber (Figure 1), and given one hour to acclimate to the chamber while being exposed to zero velocity. After the initial acclimation period, test fish were forced to "warm-up" at speeds near ¼ (for fish ≤ 55 mm TL) or

½ (for fish ≥ 56 mm TL) body length per second (BLS) for one hour. After the "warm-up" period test fish were randomly exposed to one of four treatment velocities: 1, 2, 3, or 4 BLS, until swimming failure. Failure was defined as complete impingement upon the screen at the downstream end of the flume. Upon failure, water velocity in the flume was stopped, time of swimming (in seconds) was recorded, and test fish were transferred into a new holding tank. Test fish were kept isolated from non-test fish to ensure individual fish were not measured twice for swimming performance. For all velocities tested (1, 2, 3, or 4 BLS) we did not permit fish to swim > 200 minutes, and we assumed fish swimming to 200 minutes at a given velocity to be able to swim at that velocity indefinitely. For comparison swimming performance results are often reported as BLS. However, it is important to note that this is an approximation because fish lengths varied within each size class reported.

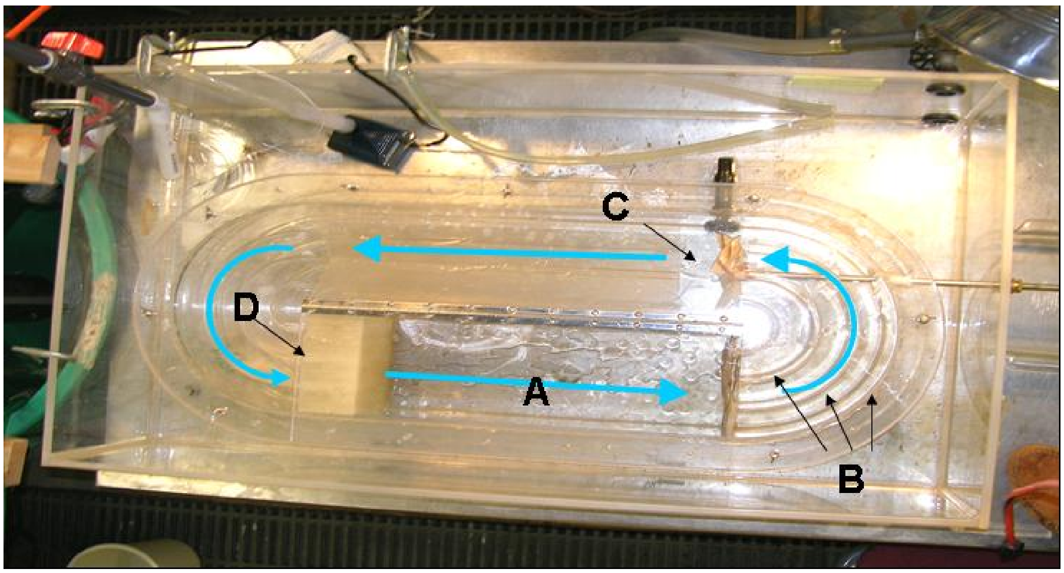

Figure 1. Overhead view of the fish swimming flume depicting the swimming chamber (A), adjustable veins (B), propeller (C), and adjustable honeycomb filter (D). Light blue lines are indicative of the direction of flow.

Screen Impingement Survival

The screen impingement survival study was designed to evaluate effects of screen impingement, as a function of impingement time, on mortality rates of larval and juvenile Pallid Sturgeon. To test impingement induced mortality, the test apparatus was designed using 1.75 mm wedge wire screen (NOAA salmonid criteria) mounted normal to flow in a 0.3 m wide Plexiglass channel (Figure 2). For all replicates, the screen was oriented with the wedge wire mounted in a horizontal position. For screen impingement survival tests, screen bypass was not provided, and all fish were exposed to flows passing through the screen.

To measure the effects of screen impingement on Pallid Sturgeon survival, a series of impingement tests using three age-classes of larval fish were conducted: 10 day old (13 – 15 mm TL, n = 5), 16 day old (14 – 17 mm TL, n = 10), 24 day old fish (14 – 18 mm TL, n = 2) (Table 1-2A, B, and C), and one group of 44 day old juvenile fish (37 – 60 mm TL, n = 13). For each replicate employing the use of larval fish (< 30 mm TL), sturgeon were introduced to the flow 30 cm upstream of the screen at mid-water depth and continuously exposed to a velocity of 12 cm/s. Whereas juvenile fish (> 30 mm TL) were initially exposed to a velocity of 12 cm/s (0.4 ft/s), after which the screen approach velocity was then increased in steps to 30.5 cm/s (1.0 ft/s). All fish were tested until impinged on the screen or until they passed through the screen. Impingement was defined as fish entrapment on the upstream face of the screen. To test temporal affects of impingement, fish were left on the screen and monitored for periods of 2, 5 and 10 minutes, after which they were unimpinged by creating a reverse flow through the screen and collected to evaluate 48-hour mortality. For each replicate, control fish were netted and handled in the same manner as test fish but were not exposed to the screen.

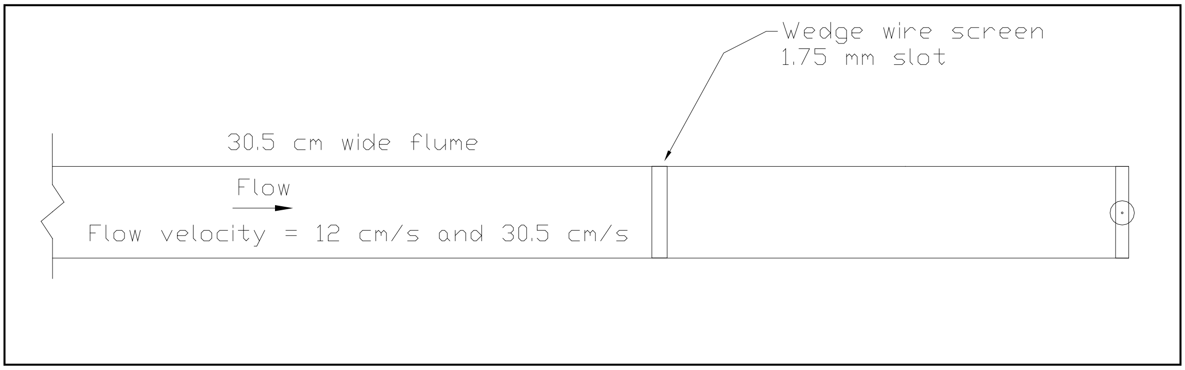

Figure 2. Plan view of fish screen impingement survival test apparatus.

Screening Effectiveness Based on NOAA Salmonid Fry Criteria

The Lower Yellowstone Irrigation District Main Canal screening concept (Christensen et al. 2005) is based on applying NOAA salmonid fry criteria as the basis of the fish screen design. This experiment was designed to investigate the effectiveness of salmonid fry criteria for Pallid Sturgeon < 100 mm TL. To test the applicability of NOAA salmonid fry criteria for young Pallid Sturgeon, a test apparatus was developed consisting of an 8.04 m long fish screen structure containing six 0.91m long by 0.61m high vertical wedge wire screen panels installed in an 18.3 m long by 1.0 m wide laboratory flume. The screen structure was angled to the flow at 6.8°, the half angle of the "V" screen concept proposed for the Main Canal at Intake Diversion Dam (Figure 3a, 3b). Upstream of the screen a 2.56 m long solid panel transitioned flow onto the screen. Downstream of the screen, fish and bypass flow passed through a 13 cm wide bypass channel leading to a circular fish collection tank. The screen panels were oriented with the wedge wire running horizontal, and a flow of 0.24 m^3/s was delivered to the test flume during all replicates. The average depth along the screen was 0.43 m. Screen sweeping velocity (parallel to the screen) increased along the screen from 0.73 m/s (2.4 ft/s) upstream to 0.85 m/s (2.8 ft/s) upstream of the bypass entrance. Screen approach velocity (velocity component normal to the screen face measured 7.6 cm (3 inches) in front at mid-depth) varied between 9.7 cm/s and 11.5 cm/s (0.32 and 0.38 ft/s). A screen flow baffle was installed behind the downstream most screen panel to control approach flow velocity. The average ratio of sweeping to approach velocity along the screen was 7.7.

As a means to measure screening effectiveness employing the use of NOAA salmonid fry criteria, sturgeon were randomly released at three varying depths within the test apparatus using a 5 cm diameter plastic tube: a few inches off the bottom, at mid-depth and near the water surface. The release tube was held vertical to the flow resting on the channel bottom. For each replicate, fish were inserted into the tube and the tube was then raised to the desired depth. The tube was then rotated upstream until it was lying horizontal in the flow. When rotated upstream, a current flowed through the tube and carried fish out. Fish generally exited the tube swimming into the flow.

Tests of screening effectiveness based on NOAA salmonid fry criteria were conducted with the insertion tube situated in one of two positions in the channel: 4.6 m upstream of the screen and at mid-channel (n=4, Table 2-3A) and 1.5 m upstream and adjacent to the screen guide wall (n= 5). Given the lack of available sturgeon, only two controls were completed to coincide with fish inserted 4.6 m upstream of the screen.

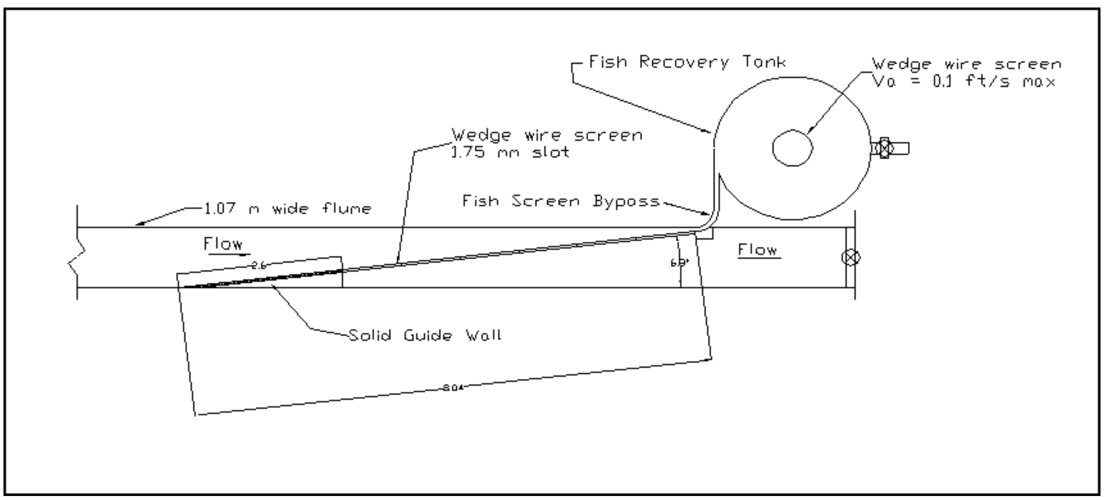

Figure 3a. Plan view of screening effectiveness test apparatus.

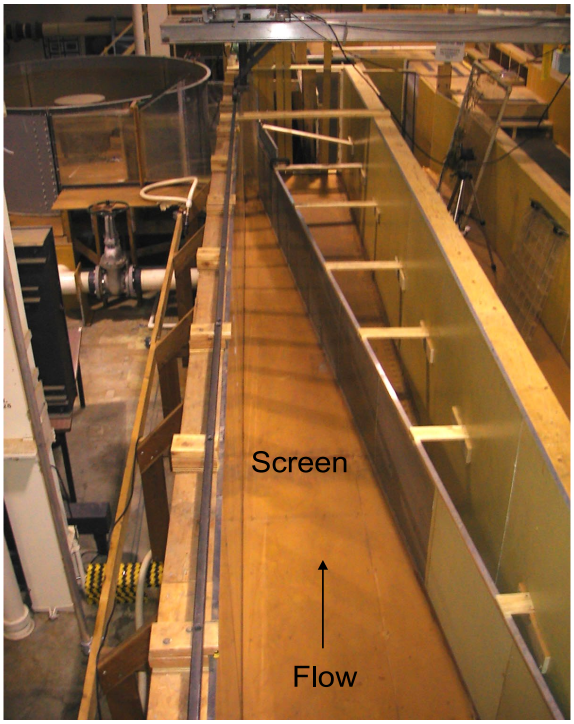

Figure 3b. Photograph of screening effectiveness test apparatus.

Recovery of Screen Impinged Fish

Active fish screens are designed to protect fish by drawing flow to the screen at an angle to the screen face. With attack angles (angle of the screen to the average flow direction) < 45° the flow velocity component into the screen (approach velocity) is less than the velocity component parallel to the screen face (sweeping velocity). Impingement on the screen is avoided by fish swimming into the flow at or greater than the screen approach velocity until the sweeping velocity carries the fish passed the screen. Since larval sturgeon are poor swimmers and likely not capable of avoiding screen impingement (see Results), the experiment was designed to evaluate the viability of recovering larval sturgeon following screen impingement. The test apparatus consisted of a 1.22 m tall Hydrolox[1] traveling plastic belt fish screen mounted normal to the flow in a 1.0 m wide flume (Figure 4a, 4b). The screen was sloped downstream at 30° from vertical.

To test the ability of sturgeon to recover from impingement on the traveling plastic belt screen, two size classes of young Pallid Sturgeon, < 15 mm and 30 – 80 mm TL, were inserted into the test apparatus upstream of the traveling screen and exposed to a screen approach velocity of 12 cm/s (0.4 ft/s) until impinged. Once impinged, a low-pressure spray wash mounted above the top of the screen washed impinged larval sturgeon off the screen and into a recovery trough.

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[1] Hydrolox is a commercially manufactured traveling fish.

Screen belt speed and flow depth on the screen were varied during the testing to evaluate duration of out-of–water recovery to determine if atmospheric exposure, post entrainment, affected sturgeon survival.

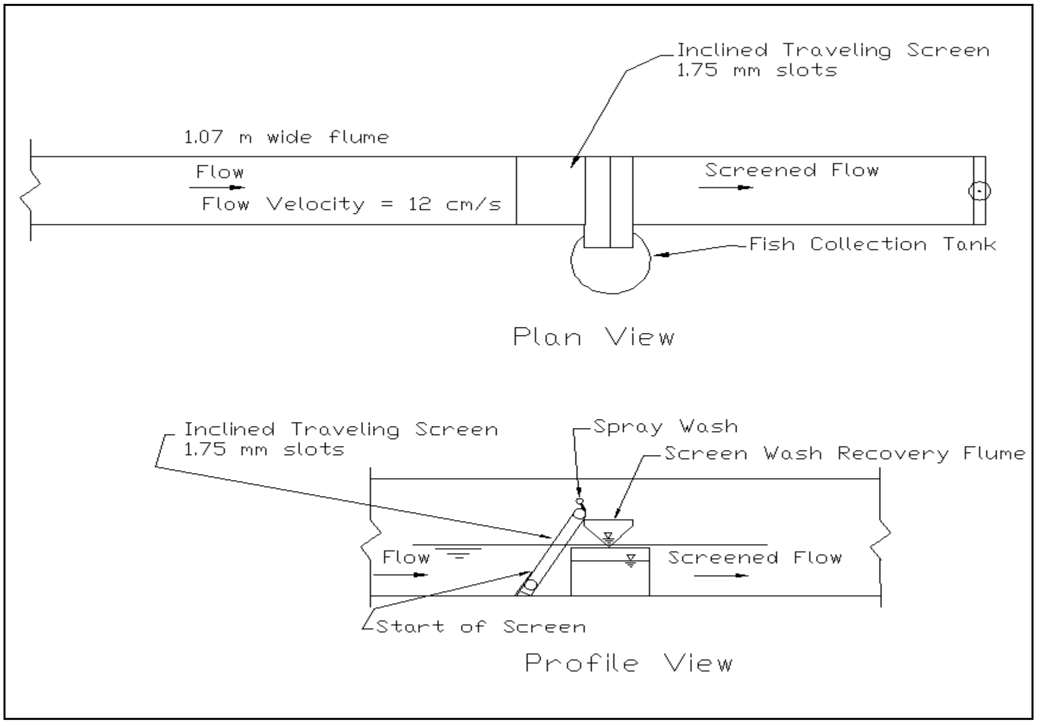


Figure 4a. Plan and profile views of Pallid Sturgeon screen impingement recovery test apparatus.

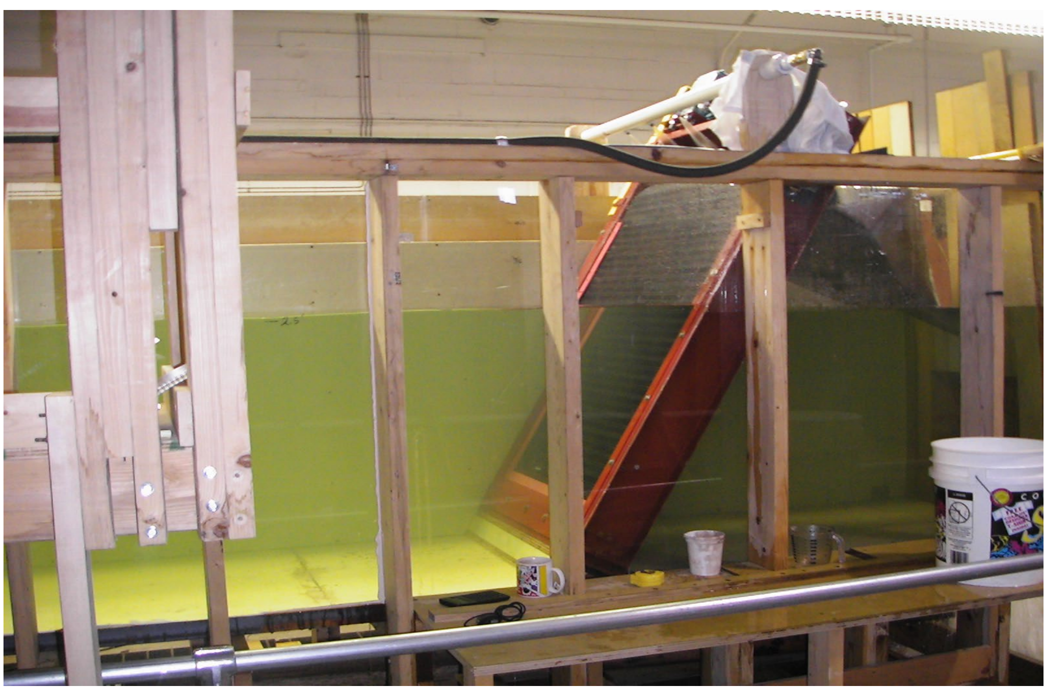


Figure 4b. Pallid sturgeon screen impingement recovery test apparatus.

RESULTS AND DISCUSSION

Swimming Endurance

Size classes of larval fish tested during the swimming endurance experiments were: 12-17, 18-25, 26-35, 36–45, 46–55, 56–65, 66-75, and 76-85 mm total length (TL). During testing, temperatures were selected to mimic likely temperatures that larval fish are exposed to in the Yellowstone River, and ranged between 16.0 – 18.2 °C. The results of our swimming endurance experiment are summarized below (Figure 5), and separated according to different size classes of fish tested:

Size Class 1: 12.0 to 17.0 mm TL

Test fish in the smallest size class tested (mean ± standard deviation (SD) = 15.1 ± 0.6 mm TL) were unable to swim when exposed to velocities equivalent to 2 body lengths per second (BLS; 0.03 m/s; n=3). When tested at 1 BLS (0.016 m/s; n = 28) swimming time ranged between 3 and 114 seconds, and the mean ± SD swim time was 25.4 ± 27.5 seconds. Many of the test fish within this size class were unable to swim against velocities equivalent to ¼ BLS during the "warm-up" phase of the experiment.

Size Class 2: 18.0 to 25.0 mm TL

Test fish in the second size class (mean ± SD = 20.3 ± 4.0 mm TL) were also unable to swim when exposed to water velocities equivalent to 2 BLS (0.03 – 0.04 m/s; n=2). When tested at water velocities between 0.016 and 0.023 m/s (1 BLS; n=3) swim time before failure ranged between 5.4 and 85.1 seconds, and the mean (± SD) swim time was 54.2 ± 42.7 seconds.

Size Class 3: 26.0 to 35.0 mm TL

No data was collected for this size class of Pallid Sturgeon.

Size Class 4: 36.0 to 45.0 mm TL

Pallid Sturgeon in the fourth size class (mean ± SD = 41.6 ± 1.8 mm TL) were unable to swim when exposed to a velocity of 0.16 m/s (4 BLS; n=1) and only swam a short period of time (mean ± SD = 8.5 ± 9.2 seconds) when exposed to 2 BLS (0.076 – 0.09 m/s). Within this given size class of Pallid Sturgeon, only one fish was tested at 1 BLS, and was only capable of swimming for 47 seconds until failure (impingement).

Size Class 5: 46.0 to 55.0 mm TL

This was the first size class (mean ± SD = 54.0 ± 0.9 mm TL) at which fish were able to swim at a water velocity equivalent to 4 BLS (0.21 m/s, n=2) for a short period of time (mean ± SD swim time = 46.3 ± 40.7 seconds). The mean swimming times (± SD) for test fish exposed to 2 BLS (0.11 m/s; n=3) and 1 BLS (0.076 m/s; n=2) were 466.3 ± 125.6 and 877.8 ± 172.9 seconds, respectively. When interpreting this data, it should be taken into consideration that the water velocities generated to measure performance at 1 BLS, were actually closer to 1.5 BLS.

Size Class 6: 56.0 – 65.0 mm TL

When fish of size class 6 (mean ± SD = 61.4 ± 2.5 mm TL) were exposed to velocities between 0.23 and 0.25 m/s (4 BLS) we first observed a "hold-slide-swim" (HSS) approach that permitted one of the test fish to avoid swimming failure at this velocity for 1832.0 seconds. During HSS, a sturgeon would "hold" position as long as possible by angling their snout downward, arching their back, and pressing their pectoral fins out and downward. Fish would maintain this position while slowly sliding backwards in the flume, until it was necessary to re-establish a position at the front of the flume, at which point they would swim forward and begin the HSS process again. The HSS technique was employed by one of the fish at this velocity, the mean swimming time for the remaining fish (n=3) exposed to velocities between 0.23 and 0.25 m/s, was 10.7 ± 9.4 seconds. At this size class, a single fish was tested at 3 BLS (0.2 m/s) and swam for 45.1 seconds. The mean swimming times for test fish exposed to 2 BLS (n=2; 0.12 m/s) and 1 BLS (n=2; 0.06 m/s) were 4755.5 ± 1760 and 10938.5 ± 1501.2 seconds, respectively.

Size Class 7: 66.0 to 75.0 mm TL

All fish in this size class (mean ± SD = 69.2 ± 3.8 mm TL) exposed to velocities equivalent to 4 BLS (n=3; 0.21 – 0.25 m/s) employed the HSS technique to maintain position in the flume and maximize their swimming time to failure, resulting in mean time to failure at velocities between 0.21 and 0.25 m/s of 1342.7 ± 1532.7 seconds. When tested at 2 BLS (n=3; 0.14 m/s) two of the three fish swam for the entire duration (12000 seconds) and the other swam for 9238 seconds prior to failure. All fish tested at 1 BLS (n=1) swam the entire duration.

Size Class 8: 76.0 – 87.0 mm TL

Test fish in the largest size class (mean ± SD = 79.2 ± 2.3 mm TL), employed the HSS technique when exposed to 4 BLS (n=1; 0.42 m/s) and 3 BLS (n=2; 0.29 m/s), and displayed mean swimming times of 2008.0 and 11272.0 ± 1029.6 seconds, respectively. When exposed to water velocities equivalent to 1 BLS (n=1) and 2 BLS (n=1), test fish were able to avoid swimming failure for the entire duration of testing.

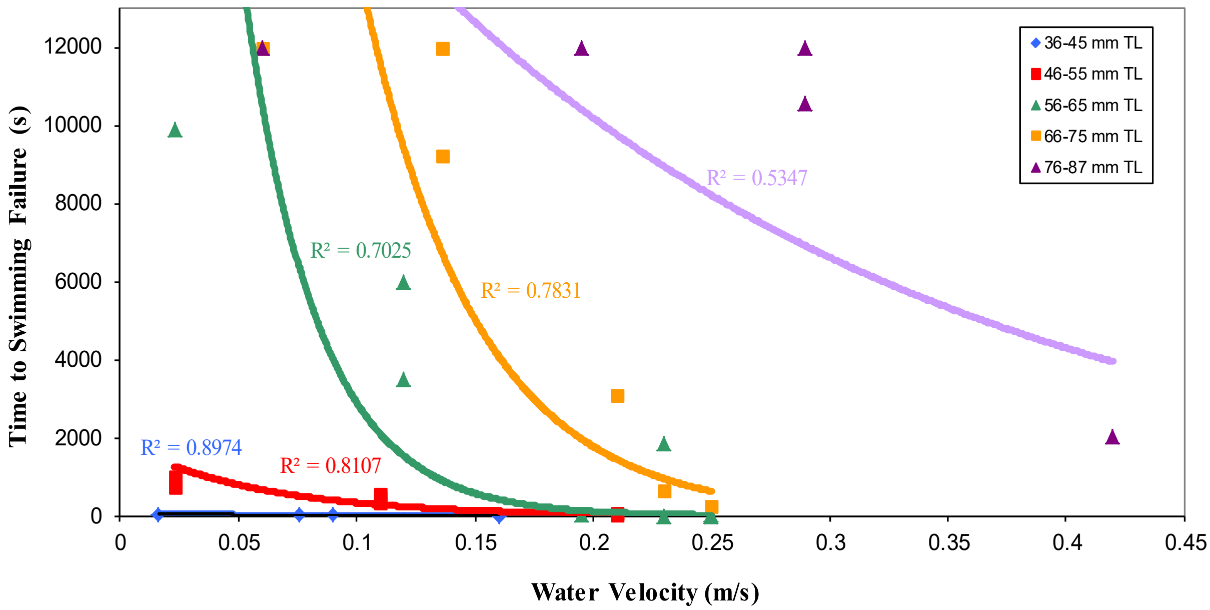


Figure 5. Swim endurance of early life-stages of Pallid Sturgeon presented using exponential regression curves of best fit.

Due to the number of fish available, the lengthy amount of time required for each individual swimming replicate, and the rapid growth of our test fish, we were unable to achieve significant sample sizes for fish swimming trials in 2007, and therefore, no statistical comparisons were attempted, and data should be interpreted with this consideration. It is also important to consider the HSS technique employed by larger sturgeon during testing may not be similar under natural conditions, as non-uniform substrate in most lotic systems does not likely promote similar flow conditions.

Screen Impingement Survival

Results of the screen impingement survival experiment indicate all 10-day old Pallid Sturgeon (14 mm mean TL, n = 5) drifted through the screen, passing through without any apparent impingement or delay, and ultimately incurred no acute mortality (Figure 6). Given that no impingement occurred with 10-day old fish, test fish were not retained to evaluate 48-hour survival.

All 16-day old Pallid Sturgeon used in the second set of tests again passed through the wedge wire screen with no impingement and no immediate mortality. However, all test fish were collected, and 48-hour survival was assessed. After 24 hours, four mortalities occurred in the test fish and one mortality occurred in the control group. No further mortalities in either group occurred during the 48-hour observation period.

During our third set of impingement tests assessing ~ 24-day old sturgeon (16 mm mean TL), four of the test fish (14 – 17 mm TL) passed through the screen without impinging, and a single 18 mm (TL) fish impinged on the screen for 110 seconds, then passed through. There were no immediate mortalities. After 24 hours, one test fish that passed immediately through the screen died and one control fish died. After 48 hours, no additional mortalities of test fish occurred, while two additional mortalities occurred in the control group.

Figure 6a. Photograph of a 15 mm Pallid Sturgeon.

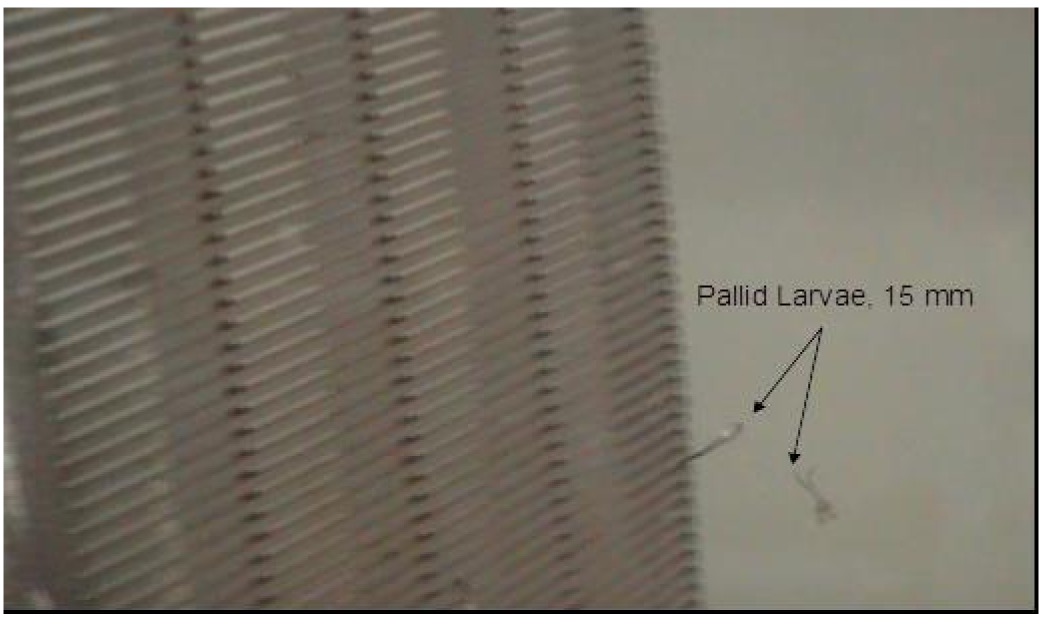


Figure 6b. Photograph of 15 mm Pallid Sturgeon larvae drifting toward 1.75 mm wedge wire fish screen.

Juvenile Pallid Sturgeon used during screen impingement tests tended to display increased swimming abilities compared to larval fish, and upon release typically swam into the flow while drifting slowly downstream until they touched the screen. After initially touching the screen, they swam upstream away from the screen staying near the bottom. Some juvenile fish were able to swim for over one hour during which they remained upstream of the screen. The screen approach velocity was then increased in steps to 30.5 cm/s (1.0 ft/s) where fish generally impinged on the screen within a few minutes and could not escape. Sturgeon typically rolled on the screen after impinging until they were lying with their mouth flat against the screen surface.

Pallid Sturgeon exposed to screen impingement for two minutes (38 mm mean TL, n = 3) survived the 48-hour observation period (Table 1-2D). It is important to note that no controls were included in the two-minute impingement test. Similarly, all sturgeon exposed to impingement for five minutes (48 mm mean TL, n = 5) and ten minutes (45 mm mean TL, n = 5), as well as control fish (n = 5 for both five- and ten-minute impingement studies) used during these replicates, survived for 48 hours post-impingement (Table 1-2E and Table 1-2F). The only noticeable difference between fish exposed to impingement for two minutes compared to fish exposed for five and ten minutes of impingement was that sturgeon exposed to five and ten minutes of impingement occasionally moved their caudal fins, apparently in an attempt to dislodge from the screen.

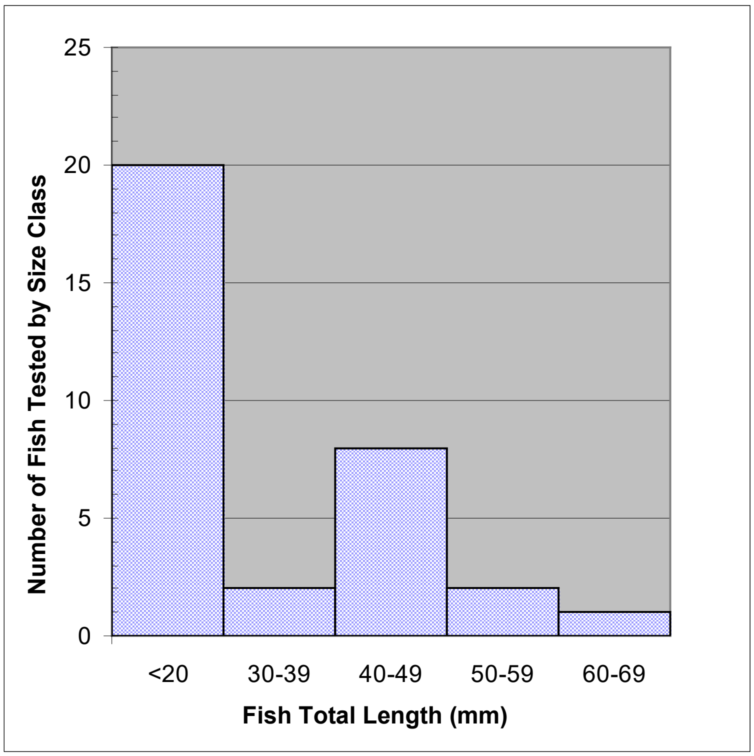


Figure 7. Size distribution of Pallid Sturgeon used in fish screen impingement survival tests.

Table 1. Screen impingement survival test data.

Date	Series/Test Set	Velocity cm/s	Fish #	Length mm	Mortality 24 hr	Mortality 48 hr	Fish Impinged	Comments
	2/A							
7/3/2007	2 min impingment	12	1	13			no	* All fish passed through 1.75 mm wedgewire screen
			2	14			no	with no impingment observed on screen. Fish were
			3	14			no	not recovered
			4	15			no	
			5	14			no	
	2/B							
7/9/2007	2 min impingment	12	1	15	0	0	no	* All fish passed through 1.75 mm wedgewire screen
			2	16	0	0	no	with no impingment observed on screen. Fish were
			3	15	1	N/A	no	recovered.
			4	14	0	0	no	
			5	14	1	N/A	no	
			6	15	1	N/A	no	
			7	15	0	0	no	
			8	17	0	0	no	
			9	14	0	0	no	
			10	15	1	N/A	no	
	Control fish		1	14	0	0		
			2	15	1	N/A		
			3	15	0	0		
			4	14	0	0		
	2/C							
7/16/2007	2 min impingment	12	1	16	0	0	no	
			2	14	1	N/A	no	
			3	18	0	0	< 120 sec	*impinged on screen for 110 sec then passed through
			4	16	0	0	no	
			5	17	0	0	no	
	Control fish		1	16	0	0		
			2	17	0	0		
			3	15	1	N/A		
			4	17	0	1		
			5	15	0	1		
	2/D							
8/13/2007	2 min impingment	30.5	1	37	0	0	yes	* Fish swam upstream at 12 cm/s velocity.
			2	40	0	0	yes	Fish swam near bottom for over 1 hour before impinging
			3	38	0	0	yes	Channel velocity was slowly increased to 30.5 cm/s
	No controls							where fish impinged within a few minutes.
	2/E							
8/14/2007	5 min impingment	30.5	1	47	0	0	yes	
			2	50	0	0	yes	
			3	40	0	0	yes	
			4	45	0	0	yes	
			5	60	0	0	yes	
	Control fish		1	42	0	0		
	2/F							
8/15/2007	10 min impingment	30.5	1	40	0	0	yes	
			2	43	0	0	yes	
			3	45	0	0	yes	
			4	52	0	0	yes	
			5	45	0	0	yes	
	Control fish		1	45	0	0		

Screening Effectiveness Based on NOAA Salmonid Fry Criteria

Following release of sturgeon from the insertion tube situated 4.6 m upstream of the screen all fish swam actively into the flow. The time required for flow to travel the length of the screen was 7.2 seconds, and the average time for sturgeon to pass the screen was 9 seconds. The small difference in travel times indicates larvae used active swimming only as a means to maintain orientation and did not display significant forward propulsion to avoid downstream drift. Although characteristic of all fish tested, it is plausible that a different behavior may be observed if fish were conditioned to flowing water for longer periods prior to testing.

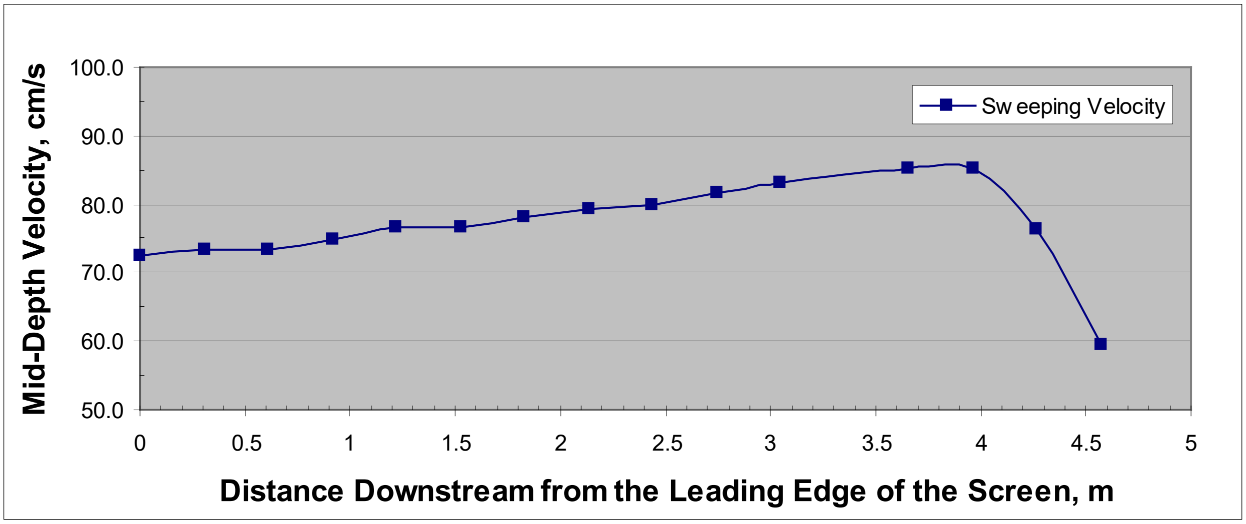
Five sets of screen effectiveness tests were conducted over a two-month period during which fish were released with the insertion tube located 1.5 m upstream and adjacent to the screen guide wall. Water velocities measured 7.6 cm in front of the screen at mid-depth are provided in Figure 8. Flow velocities represent 30 second averages measured with a 3-dimensional acoustic velocity meter. The test results for sturgeon larvae released adjacent to the screen are given in Tables 2-3B through 2-3G. As fish drifted downstream in the flow, visual observations of swimming orientation and position in the water column were noted. During test 2B, the time that fish were exposed to the screen was recorded. Eight fish were tested ranging in size from 36 to 60 mm TL. Average time required for fish to pass the length of the screen was 8.4 seconds. All fish survived the 48-hour observation period. Test sets 2-3C through 2-3G were conducted similar to 2-3B, except number of screen touches was recorded. For the purposes of analysis these tests were combined. The combined set includes 47 treatments and 11 controls. Number of treatment and control fish by size class is provided in Figure 9. The number of test fish and control fish in each size class chosen for the study were based primarily on fish availability, and fish were randomly selected from holding tanks. As a result, the number of fish in each size class typically represented the size distribution of fish available for testing. The screen tests resulted in no immediate mortalities. Three mortalities occurred during the first 24 hours following the tests and two between 24 and 48 hours. No mortalities occurred in control groups.

Table 2. Screening effectiveness test data.

Date	Series/Test Set	Fish #	Length mm	Mortality 24 hr	Mortality 48 hr	No. of screen touches	Time to pass screen sec	Comments
								Ave. Screen Sweeping Velocity = 70 cm/s
	3/A							Ave. Screen Approach Velocity = 12 cm/s
8/15/2007	Concept Design	1	60	0	0	N/A	9	No fish were tested until they were large
		2	60	0	0	N/A	8	enough to not pass through the screen
		3	40	0	1	N/A	10	Screen - 1.75 mm wedgewire screen with slots horizontal
		4	40	0	1	N/A	9	Test Flow - 0.235 cms at 36.5 cm depth
	controls	1	42	0	0	N/A		Fish inserted at channel centerline 4.6 m upstream of screen
		2	46	0	0	N/A		
	3/B							
8/16/2007	Concept Design	1	60	0	0	N/A	7	Fish were released 1.5 m upstream and
		2	60	0	0	N/A	11	next to screen using release tube
		3	60	0	0	N/A	8	
		4	52	0	0	N/A	9	
		5	41	0	0	N/A		Time it took fish to pass screen was recorded
		6	58	0	0	N/A	7	
		7	42	0	0	N/A		
		8	40	0	0	N/A		
	3/C							
8/16/2007	Concept Design	1	50	0	0	4	N/A	Fish were released 1.5 m upstream and
		2	45	0	0	3	N/A	next to screen using release tube
		3	38	0	0	3	N/A	
		4	35	0	0	5	N/A	Fish released about mid depth
		5	55	0	0	0	N/A	
		6	45	0	0	6	N/A	
		7	42	0	0	2	N/A	No impingments observed
	control	1	43	0	0		N/A	
	3/D							
8/17/2007	Concept Design	1	50	0	0	4	N/A	Fish were released 1.5 m upstream and
		2	55	0	0	1	N/A	next to screen using release tube
		3	52	0	0	0	N/A	
		4	55	0	0	5	N/A	Fish released from about 10 cm off the bottom
		5	45	0	0	4	N/A	to water surface
		6	56	0	1	4	N/A	
		7	34	1		2	N/A	Most fish actively swam at a shallow angle to screen
		8	40	0	1	2	N/A	
		9	55	0	0	2	N/A	
		10	48	0	0	0	N/A	No impingments observed
	controls	1	33	0	0			
		2	50	0	0			
	3/E							
8/21/2007	Concept Design	1	45	1		3	N/A	Fish were released 1.5 m upstream and
		2	36	0	0	2	N/A	next to screen using release tube
		3	55	1		1	N/A	
		4	70	0	0	1	N/A	
		5	60	0	0	3	N/A	
		6	37	0	0	1	N/A	
		7	43	0	0	1	N/A	
		8	52	0	0	1	N/A	
		9	54	0	0	1	N/A	
		10	37	0	0	3	N/A	No impingments observed
	controls	1	41	0	0			
		2	48	0	0			

Table 2. Screening effectiveness test data (continued).

Date	Series/Test Set	Fish #	Length mm	Mortality 24 hr	Mortality 48 hr	No. of screen touches	Time to pass screen sec	Comments
	3/F							
8/21/2007	Concept Design	1	65	0	0	3	N/A	Fish were released 1.5 m upstream and
		2	60	0	0	2	N/A	next to screen using release tube
		3	58	0	0	2	N/A	
		4	59	0	0	5	N/A	
		5	58	0	0	5	N/A	
		6	60	0	0	3	N/A	
		7	50	0	0	2	N/A	
		8	59	0	0	2	N/A	
		9	63	0	0	4	N/A	
		10	49	0	0	1	N/A	No impingments observed
	controls	1	51	0	0			
		2	48	0	0			
	3/G							
10/10/2007	Concept Design	1	86	0	0	2	N/A	Fish were released 1.5 m upstream and
		2	85	0	0	3	N/A	next to screen using release tube
		3	95	0	0	1	N/A	
		4	88	0	0	3	N/A	
		5	87	0	0	2	N/A	
		6	90	0	0	1	N/A	
		7	72	0	0	3	N/A	Fish displayed reotactile swimming.
		8	91	0	0	1	N/A	They typically moved away from screen following a light
		9	82	0	0	2	N/A	touch. No impingments were observed.
		10	80	0	0	3	N/A	
	controls	1	80	0	0			
		2	82	0	0			



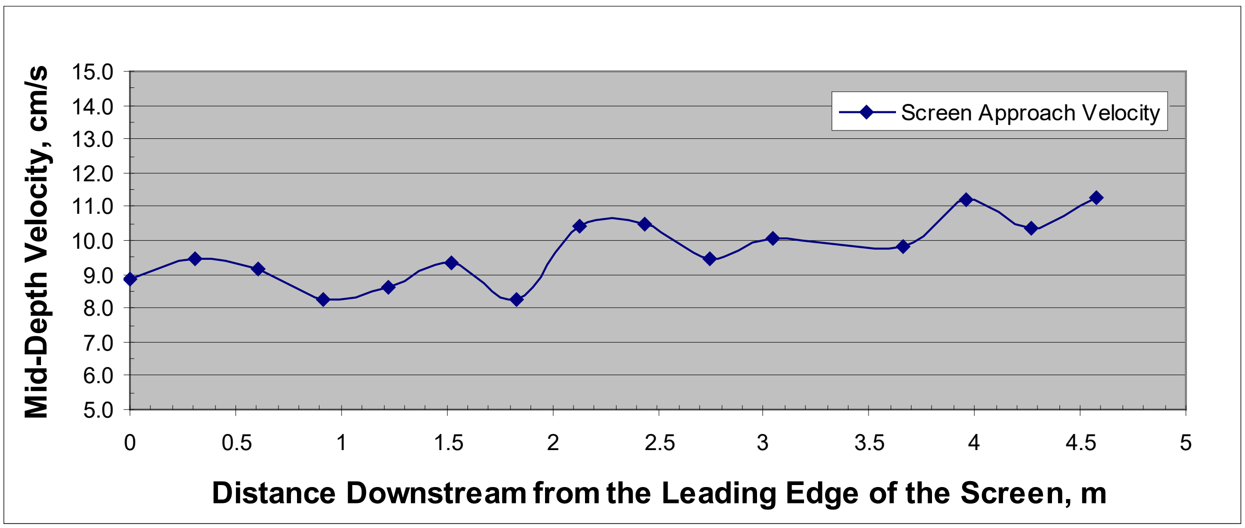


Figure 8. Fish screen sweeping and approach flow velocities measured three inches in front of the fish screen.

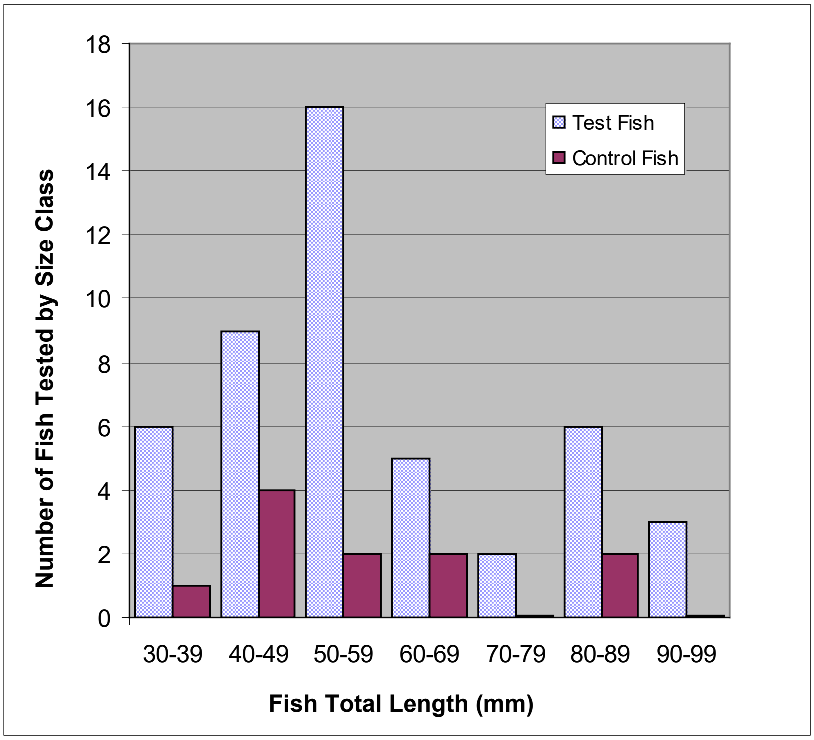


Figure 9. Size distribution of pallid sturgeon used in fish screening effectiveness tests.

Recovery of Screen Impinged Fish

Experiments were completed measuring survival of travel screen impinged Pallid Sturgeon at two size classes: < 20 mm (n = 6; group 1 fish) and > 30 mm (n = 26; group 2 fish). The size distribution of the group 2 fish test group is displayed in Figure 10. Given fish handling and holding methodology were similar for screen impingement survival and screening effectiveness tests, and experimental replicates were conducted within the same time frame, we deemed it acceptable to employ use of the same control fish for both experiments. It is also important to note that when measuring recovery of screen impinged sturgeon, fish that were not efficiently washed into the post impingement collection facility were excluded from our analysis (this scenario only occurred due to equipment failure).

All group 1 fish (< 20 mm TL) passed successfully through the traveling screen and were not impinged. Therefore, no post impingement recovery analysis was attempted with group 1 fish. However, we did observe impingement when testing group 2 fish. Six replicates were conducted using group 2 fish (38 – 60 mm TL), a screen speed of 81 cm/min, and 64 cm of screen extending above the water surface. These conditions resulted in a mean screen travel time from the water surface to the spray wash recovery located on the top of the screen of 0.74 minutes. Under these screen operation conditions the mean test fish out-of-water-time (water surface to passing over the screen) was 1.63 minutes, and the minimum and maximum times were 0.74 minutes and 3.0 minutes, respectively. When operating the screen in this manner impinged fish generally laid still on the screen as they were carried above the water surface, were easily carried up the 30-degree incline, and incurred no acute or 48 hour mortality (Figure 10). In five of the tests, fish fell back into the water prior to reaching the top of the screen and were carried up the screen more than once before being recovered.

A second set of tests was conducted using group 2 fish, and increasing the mean screen travel speed to 1.22 m/min. Operating the screen in this manner resulted in faster screen travel and a reduction in the above water screen travel time (mean above water screen time = 30 seconds), which ultimately resulted in a mean out-of-water period for fish of 85 seconds. Due to lack of available test fish, when employing this secondary operational method, experiments were limited to three replicates (fish lengths = 58, 60 and 78 mm TL) to evaluate if the shorter out-of water duration reduced the proportion of fish that fell back off of the screen as they traveled up the screen face. All three sturgeon tested using our secondary screen operating criteria were recovered, and showed no acute or 48 hour mortality. However, all test fish fell back off the screen at least once during testing.

When operating the traveling screen employing the first two operational criteria (see above) nearly all fish displayed a behavior of resting still on the screen for about 20 seconds after being carried above the water surface. Based on this observation, we wanted to test the effects of water depth on the screen to see if we could reduce the time from which fish were exposed to the atmosphere (water surface) to the point at which they reached the recovery spray wash, and also measure if this change had an affect on sturgeon survival. To test these assumptions, water depth on the screen was increased from 0.76 to 0.96 m, and the mean travel screen speed was maintained at 1.22 m/min. Twelve sturgeon (45 – 77 mm FL) were tested under these operational conditions (Table 3-4C). Operating the screen employing these methods resulted in a reduction in mean atmospheric exposure (time from the water surface to the recovery spray wash) to about 18 seconds. All fish were recovered with no immediate mortalities and no mortalities occurred during the 48 hr observation period. In the twelve tests one fish fell back once before being recovered, and out-of-water recovery times averaged 19.5 seconds for the test group.

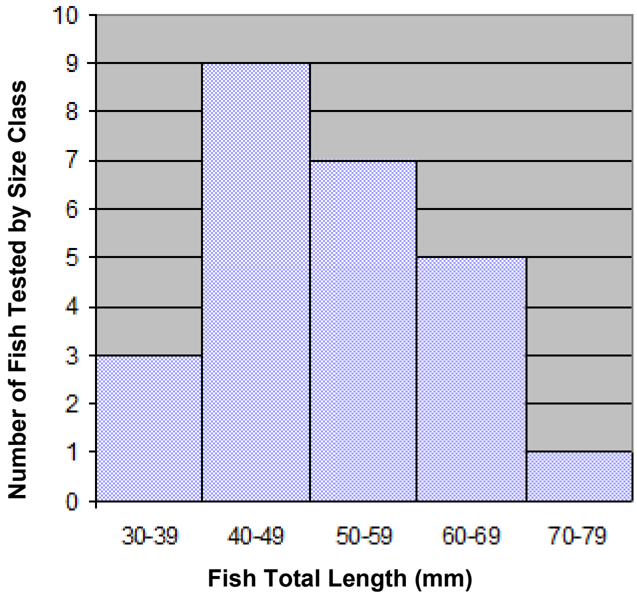


Figure 10. Size distribution of pallid sturgeon used in fish screen impingement recovery tests.

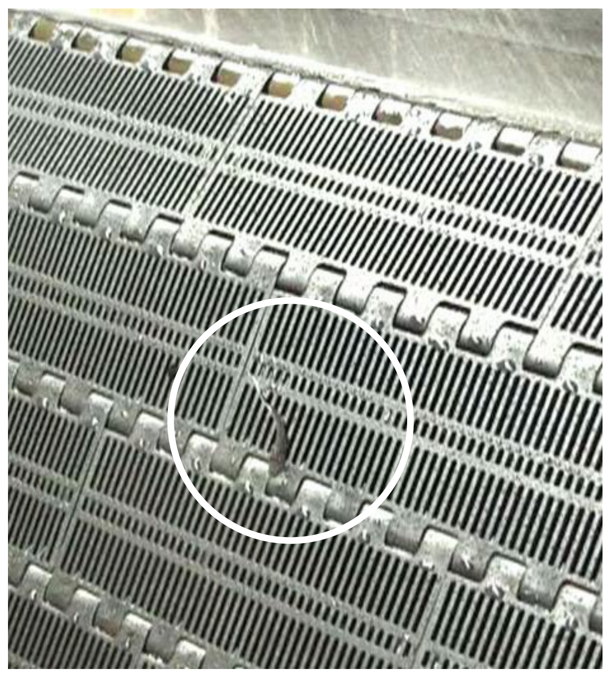


Figure 11. Photograph of Pallid Sturgeon impinged on traveling fish screen (left). Photograph on the right shows fish being lifted on the screen above the water. Spray wash at top of screen flushed fish into a recovery trough.

Table 4. Recovery of screen impinged Pallid Sturgeon test data.

Date	Test subtopic/set	Fish #	Length TL mm	Mortality 24 hr	Mortality 48 hr	Fish Impinged	Time above water surface sec	Number of fall backs	Screen speed 81 cm/min@20 122 cm/min@30	Length of screen above water surface, cm	Screen travel time from water surface to spraywash, min	Comments Ave. Screen Approach Velocity = 12 cm/s
	4/A											
7/3/2007	traveling screen	1	13			no	passed through		81	64.0	0.8	water temp = 20deg C
		2	14			no	passed through		81	64.0	0.8	Fish passed through screen and were
		3	14			no	passed through		81	64.0	0.8	not recovered
		4	12			no	passed through		81	64.0	0.8	
		5	15			no	passed through		81	64.0	0.8	
		6	14			no	passed through		81	64.0	0.8	
	4/B											
8/13/2007	traveling screen	1	30	Not recovered		yes			81	64.0	0.8	* ~48 sec from water surface to spray wash
		2	40	Not recovered		yes			81	64.0	0.8	Several fish passed over the screen
		3	37	Not recovered		yes			81	64.0	0.8	and were not washed into the recovery trough
		4	40	0	0	yes	not recorded		81	64.0	0.8	
		5	43	Not recovered		yes			81	64.0	0.8	
		6	38	0	0	yes	62	0.31	81	64.0	0.8	
		7	60	0	0	yes	48	0.01	81	64.0	0.8	
		8	55	0	0	yes	78	0.65	81	64.0	0.8	
		9	57	0	0	yes	180	2.80	81	64.0	0.8	
	4/C											
8/22/2007	traveling screen	1	60	0	0	yes	130	1.74	81	64.0	0.8	* ~48 sec from water surface to spray wash
		2	78	0	0	yes	70	1.22	122	64.0	0.5	Screen speed increased to 4.0 ft/min
		3	58	0	0	yes	55	0.75	122	64.0	0.5	
		4	60	0	0	yes	135	3.29	122	64.0	0.5	
		5	77	0	0	yes	24	0.34	122	36.5	0.3	Water depth on screen increased to 96.5 cm
		6	61	0	0	yes	22	0.23	122	36.5	0.3	to reduce the out-of-water time to minimum of 18 sec
		7	46	0	0	yes	18	0.00	122	36.5	0.3	
		8	58	0	0	yes	18	0.00	122	36.5	0.3	
		9	45	0	0	yes	26	0.45	122	36.5	0.3	
										36.5		
	Controls	1	66	0	0					36.5		
		2	64	0	0					36.5		
	4/D											
8/27/2007	traveling screen	1	55	0	0	yes	18	0.00	122	36.5	0.3	*~ 18 sec from water surface to spray wash
		2	47.5	0	0	yes	18	0.00	122	36.5	0.3	96.5 cm depth on screen tilted at 30deg. from vertical
		3	40.5	0	0	yes	18	0.00	122	36.5	0.3	
		4	60	0	0	yes	27	0.50	122	36.5	0.3	
		5	50	0	0	yes	18	0.00	122	36.5	0.3	
		6	47.5	0	0	yes	18	0.00	122	36.5	0.3	
		7	50	0	0	yes	20	0.11	122	36.5	0.3	
	No controls											

ANALYSES

Swimming Endurance

We were unable to collect a sufficient amount of data when measuring the swimming performance of larval and juvenile pallid sturgeon. The insufficient number of test fish ultimately resulted in low sample sizes and an inability to perform an appropriate statistical analysis.

Screen Impingement Survival

Statistics on these tests were not conducted due to the small sample size and a relatively high mortality rate that occurred during holding of all fish.

Screening Effectiveness Based on NOAA Salmonid Fry Criteria

We tested the hypothesis that there was no screening effect on fish mortality. A 2x2 contingency table of the tests results is given below. The value of chi-squared calculated from the data is 1.24. The value is less than 3.841, the critical value at a significance level of 5.0%. This indicates the distribution of treatment and controls are statically similar at an alpha of 0.05. Therefore, we could not show a screen effect based on the test results.

	Dead	Alive	Totals
Treatment	5	42	47
Control	0	11	11
Totals	5	51	56

We also looked at a possible relationship between fish length and number of screen touches (Figure 12). In the study, only about 2% of the variation in the data can be accounted for by a linear relationship with length. The screen tests do not show improved swimming translates into improved screen avoidance for the life stages tested. This may be due to inadequate swim conditioning prior to testing or a low avoidance response behavior to the screen.

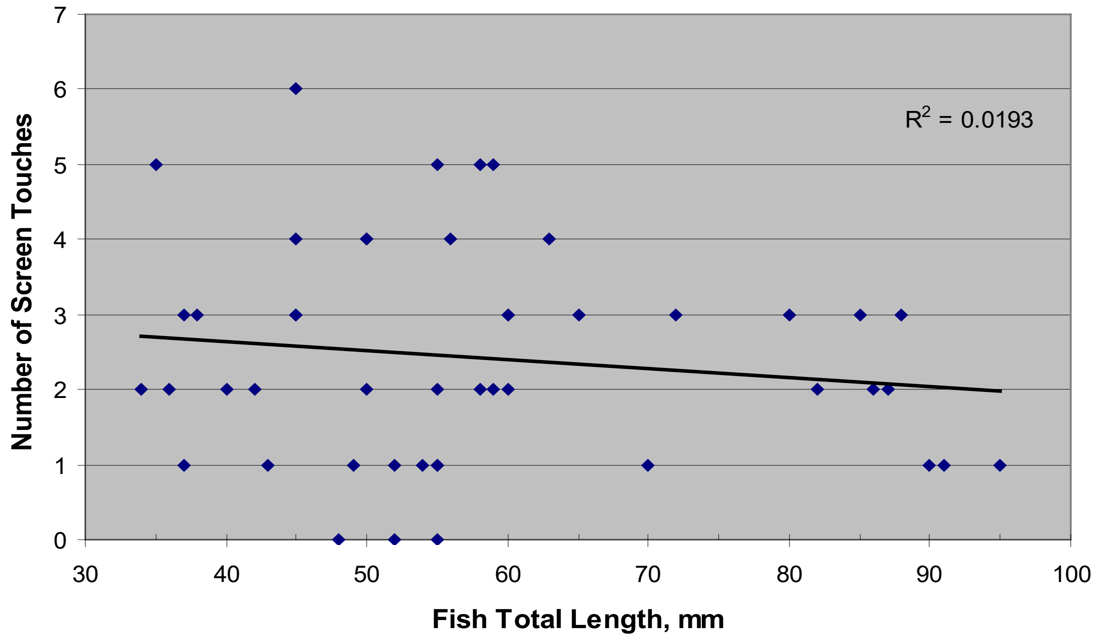


Figure 12. Linear regression of fish length versus number of screen touches during a test run.

Recovery of Screen Impinged Fish

Impingement recovery tests resulted in 100 percent survival for all fish recovered > 30 mm TL. Tests of sub-20 mm fish were not included in the analysis. Although fish survival was excellent, we were interested in relationships between fish total length and the number of times a fish fell back on the screen (Figure 13). Fall back was calculated as the total time the fish was out of water minus the screen travel time from the water surface to the screen apex divided by screen travel time from the water surface to the screen apex. The data does not indicate a strong linear relationship of fish length to fall back for the range of lengths tested.

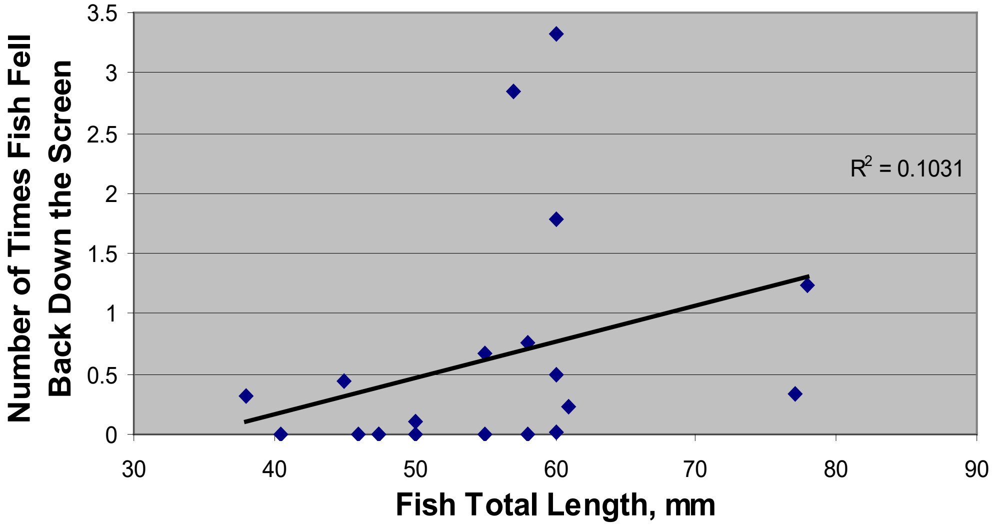


Figure 13. Linear regression of fish length versus number of times a fish fell back down the traveling screen.

CONCLUSIONS

Results of all Pallid Sturgeon experiments indicate larval fish < 20 mm possess little retractile swimming ability, and under natural conditions, most likely drift with the current, making the larval life-stage most susceptible to entrainment in flow diversions. In our laboratory experiments, fish screens designed to meet NOAA salmonid fry criteria were found to be ineffective at screening Pallid Sturgeon < 20 mm TL, as larvae < 18mm TL were found to pass easily through wedge wire screen with 1.75 mm wide slot openings. Experimental results suggest screening < 20 mm pallid sturgeon with a primary screen is likely not practical. However, results do provide some evidence that secondary screening with fine mesh screens or nets downstream of a primary screen may promote the survival of larval fish.

Pallid Sturgeon 30 – 45 mm TL also displayed poor swimming performance during all experiments. However, once fish reached this size class, they appeared to be more robust and tolerant of stressors associated with screen impingement. Results of our experiments suggest mortality rates of pallid sturgeon 30 – 45 mm TL were unaffected by impingement on the fish screen for periods as long as 10 minutes. This suggests recovery of larval pallid sturgeon > 30 mm TL that become impinged on a fish screen is viable with properly designed screen cleaning systems.

Once pallid sturgeon reached total lengths within the range of 45 – 55 mm, their swimming ability apparently improved significantly. When sturgeon reach this size range they are more likely to have swimming endurance to provide them the opportunity to avoid impingement on fish screens designed for a 12 cm/s approach flow velocity and 60 second exposure. Though the caudal fin of many fish within this size class touched the NOAA designed fish screen multiple times during testing, total number of caudal fin touches within each replicate had no effect on pallid sturgeon mortality rates.

Fish impinged on the traveling fish screen were successfully recovered when carried by the moving screen out of the water and washed into a fish bypass system. Fish generally remained still on the screen for ~ 20 seconds following dewatering. The study showed no impact on fish mortality associated with the recovery process studied.

References

Adams, R.S. et al., 1999. Swimming Endurance of Juvenile Pallid Sturgeon, *Scaphirhynchus albus,* Copeia*, No. 3 Vol. 1999, 802-807pp.*

Backes M.K. and Gardner M.W., 1994. Lower Yellowstone River Pallid Sturgeon Study III and Missouri River Pallid Sturgeon Creel Survey, Montana Department of Fish , Wildlife and Parks – Fisheries Division, Miles City Montana.

Christensen, R., Glickman A., Leavitt, M., Mefford, B. 2005, "Intake Diversion Dam, Fish Protection and Passage Concept Study Report II", Water Resources Research Laboratory, Bureau of Reclamation, Denver Co.

Hiebert, S., Wydoski, R., Parks, T., 2000. Fish Entrainment at the Lower Yellowstone Diversion Dam, Intake Canal, Montana 1996-1998, Bureau of Reclamation Denver Office Fisheries Application Group and Montana Area Office.

Hoover, J.J., et al., 2005. Paddlefish and Sturgeon Entrainment By Dredges: Swimming Performance as an Indicator of Risk, DOER Technical Notes (ERDC TN-DOER-E22) U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Kynard, B. et al., 2002. Ontogenetic Behavior, Migration, and Social Behavior of Pallid Sturgeon, Scaphirhynchus albus, and shovelnose sturgeon, S. platorynchus, with notes on the Adaptive Behavior of Body Color: Environmental Biology of Fishes, v. 63, p. 389–403.

NOAA 1997. National Marine Fisheries Service Southwest Region Fish Screening Criteria (1997) for Anadromous Salmonids (www.swr.nmfs.noaa.gov/hcd/fishscrn.pdf)

Stewart, P. A. 1986,1988,1990,1991. Fish Management Surveys, Federal Aid in fish Restoration, Project F-30-R-22, Montana Department of Fish , Wildlife and Parks, Helena.

US Army Corps of Engineers, Omaha District, 2002, "Lower Yellowstone River Intake Dam Fish Passage and Screening Preliminary Design Report".

Wildhaber et al., 2007. A Conceptual Life-History Model for Pallid and Shovelnose Sturgeon, Circular 1315, U.S. Geological Survey, Reston, Virginia