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Intake Diversion Dam Fish Screens

Evaluation of Fish Screens for Protecting Early Life Stages of Pallid Sturgeon

U.S. Department of the Interior
Bureau of Reclamation
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Water Resources Research Laboratory
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14. ABSTRACT
A laboratory study was conducted to evaluate applying NOAA salmonid fry criteria for pallid sturgeon < 100 mm total length. The study evaluated four related topics; 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 Water Resources Research Laboratory in Denver Colorado with hatchery spawned pallid sturgeon larvae provided from the Gavin's Point Hatchery. Larvae from about 14 mm to 90 mm were used in the study.

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Mission Statements

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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A laboratory study was conducted to evaluate applying NOAA salmonid fry criteria for juvenile and larval pallid sturgeon < 100 mm total length. The study evaluated four related topics; 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 Water Resources Research Laboratory located in Denver Colorado using hatchery spawned pallid sturgeon larvae provided by Gavin's Point Hatchery, South Dakota. The size range of test fish used in our studies ranged from approximately 14.0 to 95.0 mm total length (TL). Results of our lab study indicate that sub-20 mm TL larvae displayed little retractile swimming ability and easily passed through NOAA criteria fish screen material. Fish larger than about 40 mm TL were capable of swimming several minutes against a typical fish screen approach velocity of 12 cm/s. Our study results indicate NOAA salmonid fry criteria is appropriate to effectively protect pallid sturgeon > 40 mm TL. Screen impingement for periods up to 10 minutes (maximum impingement time evaluated) had no effect on fish mortality when fish were recovered by back flushing the screen. Our results also showed plastic belt inclined traveling screens can be effective for recovery of impinged juveniles.

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 the fisheries 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) show significant numbers of fish are entrained with diversion flow into the canal. Pallid sturgeon was listed as a federally endangered species in 1990 by the U.S. Fish and Wildlife Service, and is among many fish species native to the Yellowstone River system impacted by the diversion dam. Providing passage at Intake Diversion Dam and protecting sturgeon from entrainment with irrigation diversion have been identified as important links in pallid recovery. Passage at Intake Diversion Dam will open access to many miles of main stem and tributary river habitat. Wildhaber (2007) and others point out the importance of long undisturbed stretches of free flowing river habitat as being critical to larval sturgeon survival. Similarly, Kynard (2002) observed that newly hatched larval pallid sturgeon can drift downstream for up to thirteen days. During the drift period, many larval sturgeon hatched in the lower Yellowstone River are carried into Fort Peck reservoir where mortality is likely very high due to a reduction in preferential feed and increased susceptibility to predation. Given larval sturgeons life-history strategies (see Kynard 2002) it is likely that emerging larval fish, upstream of Intake Diversion Dam will incur entrainment into the Main Canal. This study investigated screening of pallid sturgeon juveniles and larvae following established National Oceanic and Atmospheric Administration (NOAA) criteria for screening salmonid fry (NOAA, 1997).

Literature Review

No prior studies of screening effectiveness for larval and juvenile pallid sturgeon were identified in our review of the literature. However, numerous studies describing the swimming performance of juvenile pallid sturgeon (> 100 mm fork length (FL)) were discovered. Understanding the swimming ability of the species of fish subjected to screening facilities as a function of life-stage is important to fish screen design. 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 fork length (FL). Maximum sustained swim speeds for the small and large size groups, subjected to temperatures between 17 - 20 ° C, were 0.10 and 0.25 m/s, respectively. In the same study, Adams reported that the 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. Hoover et al. (2005) 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 indicated that the maximum sustained swimming speeds of small and large size classes of fish tested were 0.20 and 0.35 m/s, respectively. 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 (39.2 cm mean FL). He reported that juvenile pallid sturgeon were able to swim at speeds consistent to 0.9 – 2.0 body lengths per second for several hours.

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 referred to as larval fish and fish > 30 mm TL are referred to as juvenile fish.. Four related topics were identified where data was needed. These topics were:

1. Swimming endurance for larval pallid sturgeon (<100 mm TL),
2. screen impingement survival,
3. screening effectiveness following NOAA salmonid fry criteria and,
4. recovery of screen impinged larvae.

Unique experimental designs were used to investigate each topic. A summary of the experimental design for each topic follows.

Swimming Endurance

Numerous research projects aimed at measuring the swimming performance of juvenile pallid sturgeon have been performed (see above). However, there is limited knowledge as to the swimming ability of larval pallid sturgeon, a life-stage of critical concern, commonly affected by the Intake Diversion Dam on the lower Yellowstone River. Swimming endurance curves provide an estimate of the water velocity and time a species of fish can maintain sustained, prolonged and burst swimming speeds. 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 when 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 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 can 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. Our swim flume is 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 pallid sturgeon. For each swimming performance trial, 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 $\leq$ 55 mm TL) or ½ (for fish $\geq$ 56 mm TL) body length per second (BLS) for one hour (Figure 2). 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, the 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 assure that an individual fish was 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.

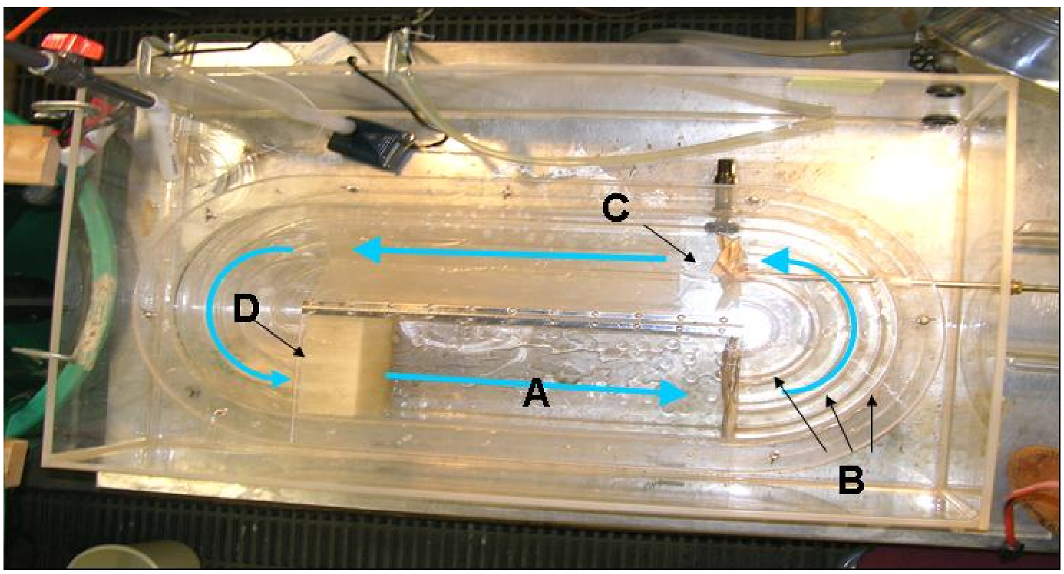


Figure 1. Overhead view of the fish swimming tunnel depicting the swimming chamber (A), adjustable veins (B), propeller (C), and adjustable honeycomb filter (D). Light blue lines are indicative of the direction of flow.

Screen Impingement Survival

The screen impingement survival study was designed to evaluate screen impingement mortality of juvenile and larval pallid sturgeon. For the purpose of this study, screen impingement was defined by fish being trapped on the upstream face of the screen. A 1.75 mm wedge wire screen was mounted normal to the flow in a 1.0 ft wide Plexiglas channel (Fig. 2). The screen was oriented with the wedgewire mounted horizontal. For these tests, no fish bypass was provided and all flows passed through the screen. Fish were introduced to the flow 30 cm upstream of the screen and allowed to swim until they were impinged on the screen. Impinged fish were left on the screen and monitored for periods of 2, 5 and 10 minutes after which they were removed by creating a reverse flow through the screen. Test fish were then held for 48 hours for observation. Larvae < 30 mm TL were impinged at a channel velocity of 0.4 ft/s. Juveniles >30 mm TL were impinged at a channel velocity of 1.0 ft/s. The higher channel velocity was required to impinge larger fish with greater swimming ability.

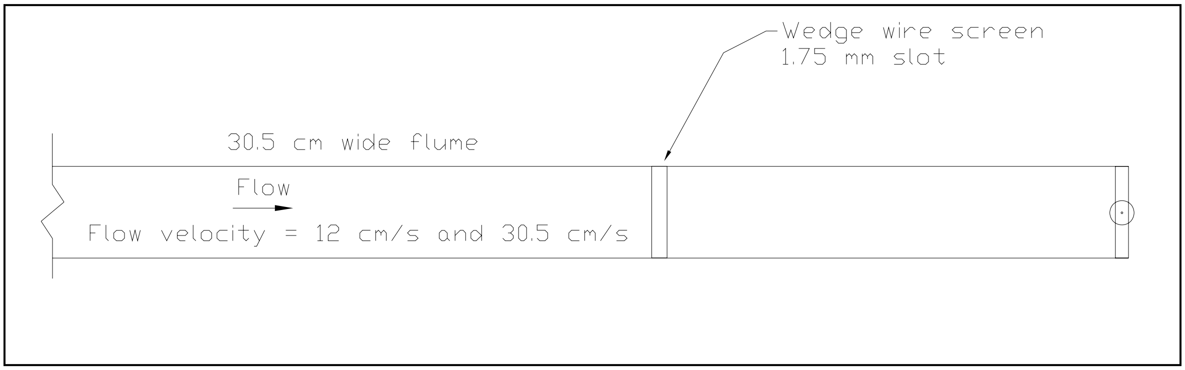
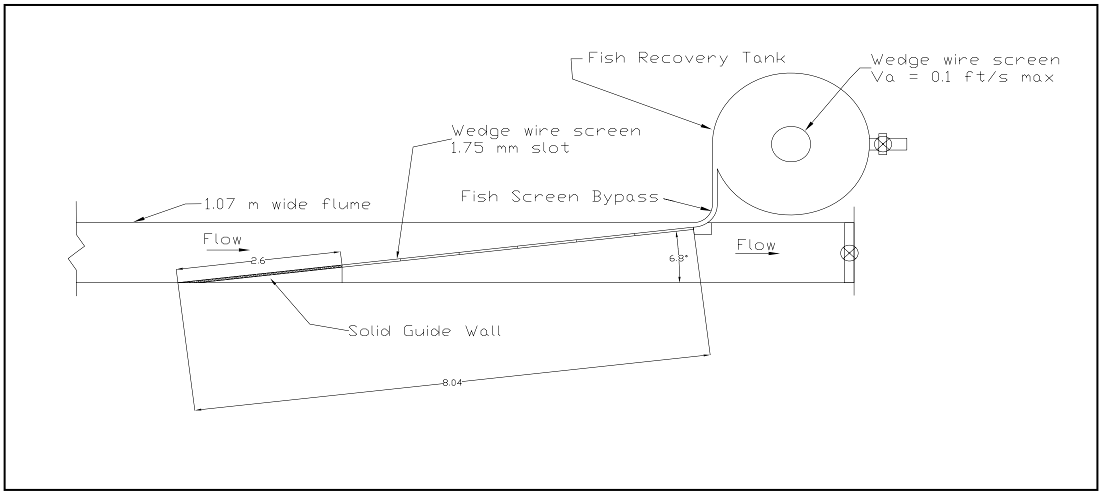


Figure 2 – Plan view of fish screen impingement survival test apparatus.

Screening Effectiveness based on NOAA Salmonid Fry Criteria

The Main Canal screening concept presented in the Concept II report (Christensen et al. 2005) is based on applying NOAA salmonid fry criteria as the basis of the fish screen design. Topic 3 was designed to investigate the effectiveness of salmonid fry criteria for pallid sturgeon < 100 mm TL. A 8.04 m long fish screen structure containing six 0.91m long by 0.61m high vertical wedgewire screen panels were installed in a 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 (Fig. 3). 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 wedgewire running horizontal. In the study, a flow of 0.235 m^3/s (8.33 ft^3/s) was delivered to the test flume. The average depth along the screen was 0.427 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. Fish were randomly released a few inches off the bottom, at mid-depth and near the water surface using a 5 cm diameter plastic tube. The release tube was held vertical in the flow resting on the channel bottom. Fish were poured into the tube and the tube then raised to approximately the desired release elevation. The tube was then rotated upstream about the end 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.



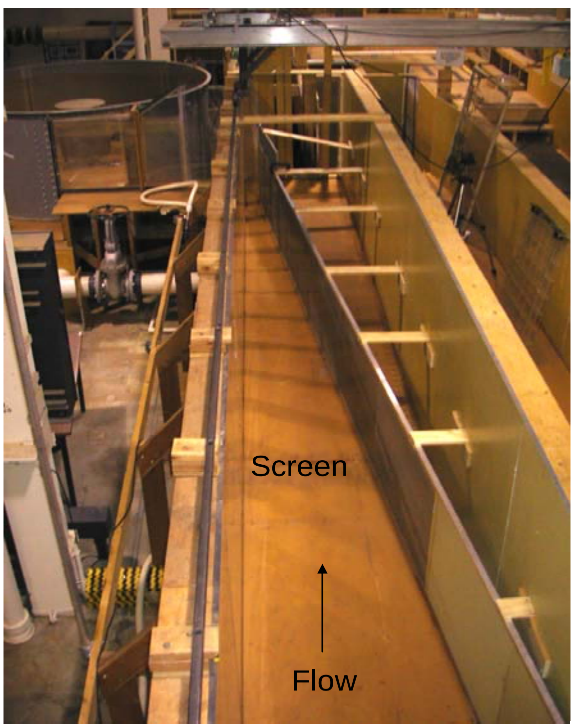


Figure 3 – Plan view and photograph of screening effectiveness test apparatus.

Recovery of Screen Impinged Larvae

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. During the drift period and early onset of swimming, larval sturgeon do not posses sufficient reotactile swimming ability to avoid screen impingement. Topic 4 was designed to evaluate the viability of recovering larval sturgeon following screen impingement. A 1.22 m tall Hydrolox[1] traveling plastic belt fish screen was mounted normal to the flow in a 1.0 m wide flume (Fig. 4 a,b). The screen was sloped downstream at 30° from vertical. A low pressure spray wash was mounted above the top of the screen to wash impinged larval sturgeon off the screen and into a recovery trough. Tests were conducted with a screen approach velocity of 12 cm/s (0.4 ft/s). Screen belt speed and flow depth on the screen were varied during the testing to evaluate duration of out-of – water recovery. Tests were conducted with sub-15mm and 30mm-80 mm TL larval fish.

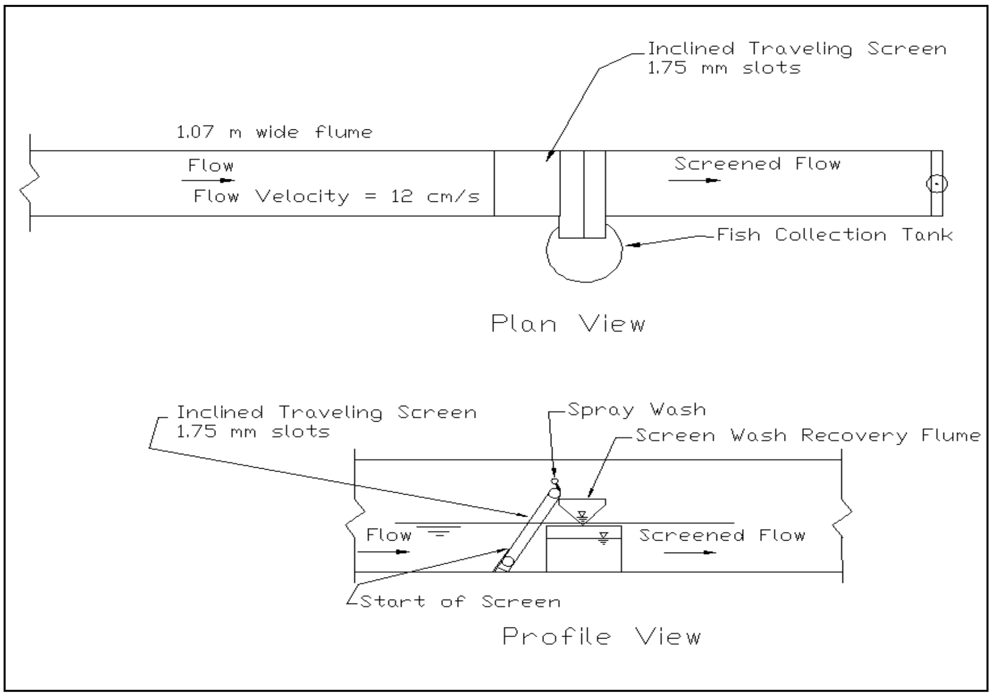


Figure 4a – Plan and profile views of sturgeon larvae screen impingement recovery test apparatus.

[1] Hydrolox is a commercially manufactured traveling fish.

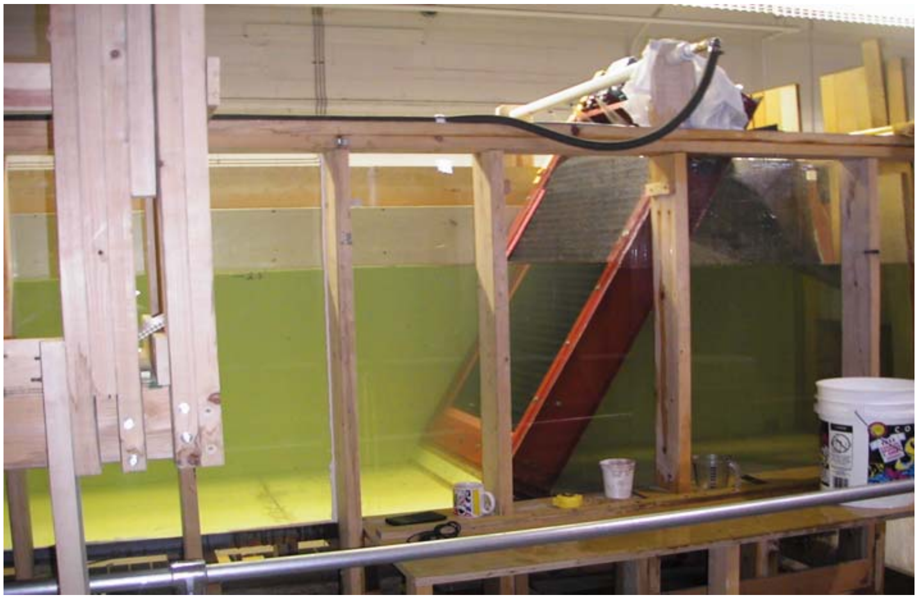


Figure 4b - Larval sturgeon screen impingement recovery test apparatus.

RESULTS and Disscussion

Three batches of approximately 300 young pallid sturgeon each were obtained from Gavins Point National Fish Hatchery (NFH) located near Yankton, South Dakota. All batches were transported by vehicle to Reclamation's Water Resources Laboratory (Lakewood, CO.). The first batch of fish consisting of approximately 9 day old larval pallid sturgeon was transported to the laboratory on July 2, 2007. The fish averaged 14 mm TL and 1 mm in width. The young larvae were held in quiescent water. Their swimming was largely limited to vertical bursts toward the water surface followed by descent to the bottom.

Larvae initiation of feeding occurs at about 10 days, Wildhaber (2007). Many researchers have identified the onset of feeding as a critical period for larvae survival and development (Gisbert and Williot, (1997); Deng et al. (2003) and Gisbert and Doroshov, (2003)). The larvae were feed a food provided by the hatchery. Generally, holding mortality of sub-25mm sturgeon larvae used in the study was generally high, likely due to problems with feeding. Once test fish reached approximately 30 mm TL, they were observed actively feeding and survival during holding was high.

Fish were acclimated to the laboratory water for two days prior to initiating tests. The initial group of hatchery fish was held for approximately 14 days. Tests of topics 1, 2 and 3 were conducted during this period. A second group of fish was transported to the laboratory approximately 21 days after hatching. These fish averaged approximately 20 mm TL, experienced high mortality during holding, and were deemed not healthy enough for test. The hatchery also experienced high larval mortality during the same period. Testing was curtailed until hatchery larval fish were felt to be feeding steadily on hatchery food. A third group of larval pallid sturgeon was transported to the laboratory in mid-August. The larvae were approximately 6 weeks old, appeared healthy, and were therefore used in our laboratory experiments. Larvae size ranged from 35 mm to 85 mm TL throughout testing.

Results - Swimming Endurance Curves

The size classes of larval fish tested during our 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 = 20) 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 (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*

At this point, no data has been collected for this size class of pallid sturgeon

***Size Class 4**: 36.0 to 45.0 mm TL*

Pallid sturgeon delineated to our 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.

***Size Class 5**: 46.0 to 55.0 mm TL*

This is 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, respectfully.

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 our final 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 (n=1) and 2 (n=1) bls, test fish were able to avoid swimming failure for the entire duration of testing.

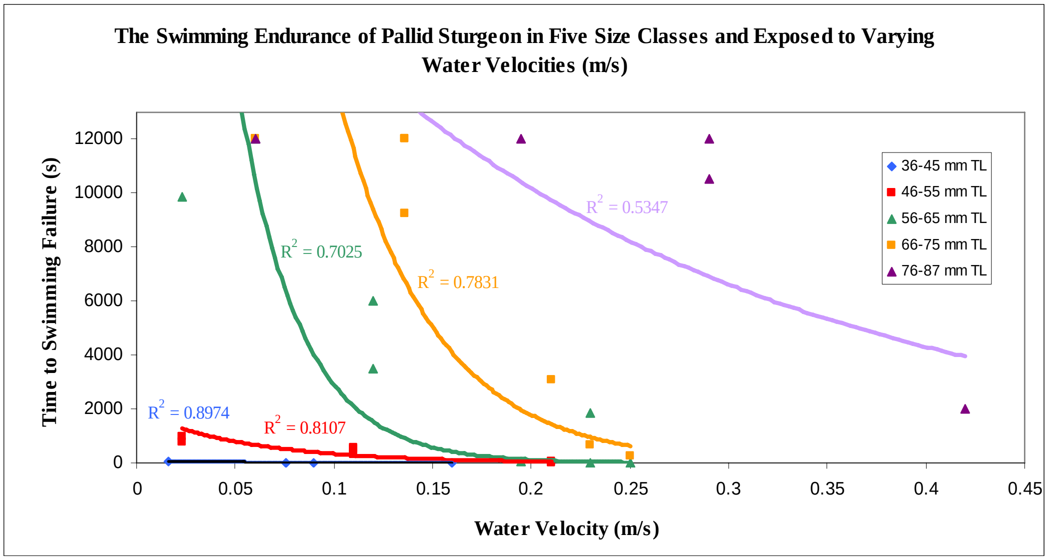


Figure 5 – Swim endurance of pallid sturgeon larvae presented using exponential regression curves of best fit.

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 our larval fish swimming trials in 2007, and therefore, no statistical comparisons were attempted. Therefore, the data collected on the swimming performance of pallid sturgeon in 2007 is preliminary, and during interpretation should be viewed as such.

Results - Screen Impingement Survival

A series of three impingement tests were conducted using sub-20mm larvae over a two week period. Initially, five ~10 day old larvae sturgeon, ranging in length from 13.0 to 15.0 mm TL (14.0 mm mean TL, n=5) were used in the study (Table 1-2A). Test fish were released as a group 30 cm upstream of the screen at mid depth. The larvae drifted to the screen and passed through without noticeable impingement or delay and incurred no initial mortality (Fig. 6). As no impingement occurred the test fish were not held for observation. Larval fish were held until they were ~ 16 days old and the impingement tests were repeated. In our second set of experiments, larval sturgeon (14.0 – 17.0 mm TL, n=10) were released one at a time and fish passing through the screen were recovered and held for observation,(Table 1-2B). Control fish were handled the same as test fish but were not exposed to the screen. All larvae used in the second set of tests again passed through the wedgewire screen with no impingement and no immediate mortality. After 24 hours, four mortalities occurred in the test fish and one mortality occurred in the controls. No further mortalities in either group occurred during the 48 hour observation period. Our third set of impingement tests were conducted using ~ 24 day old larval fish. Due to a low number of available fish, a total of ten larvae were tested. Larvae were divided into two groups of five test fish and five control fish. Test fish in the third set ranged between 14.0 and 18.0 mm TL (16.0 mm mean TL) (Table 1-2C). Four of the test fish (17mm to 14mm TL) passed through the screen without impinging. An 18 mm TL larva 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. Two additional mortalities occurred in the control group.

Figure 6a – 15 mm pallid sturgeon larva

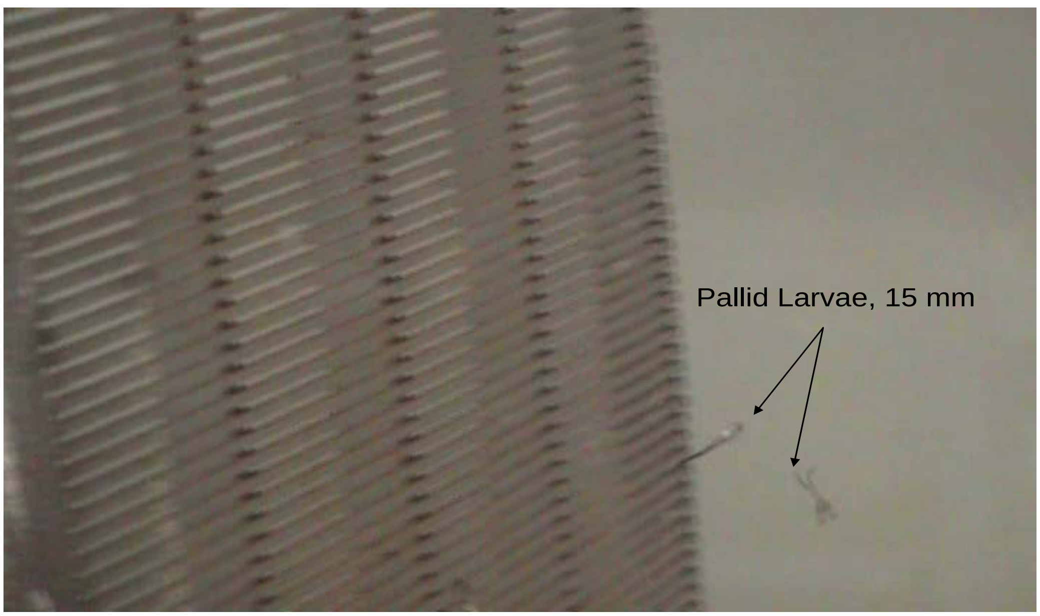


Figure 6b – Photograph of 15 mm pallid sturgeon larvae drifting toward 1.75 mm wedgewire fish screen.

The third batch of fish received from the hatchery were ~44 days old. These fish were considered young juveniles with total body lengths ranging between 37mm and 60mm. Due to the limited number of fish available to complete all tests, small numbers of fish were used for the screen impingement testing. Two, five and ten minute impingement tests were completed using the third group of fish. Initially, fish were released into a flow velocity of 12 cm/s (0.4 ft/s). Upon release, the fish typically swam into the flow while drifting slowly downstream until they touched the screen. After touching, they swam upstream away from the screen staying near the bottom. Some were allowed 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. Three fish with an average TL of 38mm were impinged on the screen for two minutes then recovered and held for 48 hours (Table 1-2D). All test fish survived for the 48 hour observation period. The fish typically rolled after impinging until they were lying with their mouth flat against the screen surface. No controls were included in the test. Five test fish and one control were used for five minute impingement tests (Table 1-2E). Fish averaged 48 mm total length with a range of 40 mm to 60 mm. Test fish were impinged for five minutes then recovered and held 48 hours. All test fish and the control survived to the 48 hour observation period. Test fish displayed only an occasional tail movement while impinged on the screen. Five test fish and one control were also used for ten minute impingement tests (Table 1-2F). The test fish averaged 45mm TL with a range of 40 mm to 52 mm. All test fish were impinged on the screen for ten minutes then recovered and held for observation. All test and control fish survived to 48 hours. The fish response to being impinged was similar to prior tests with only minor movement observed during impingement.

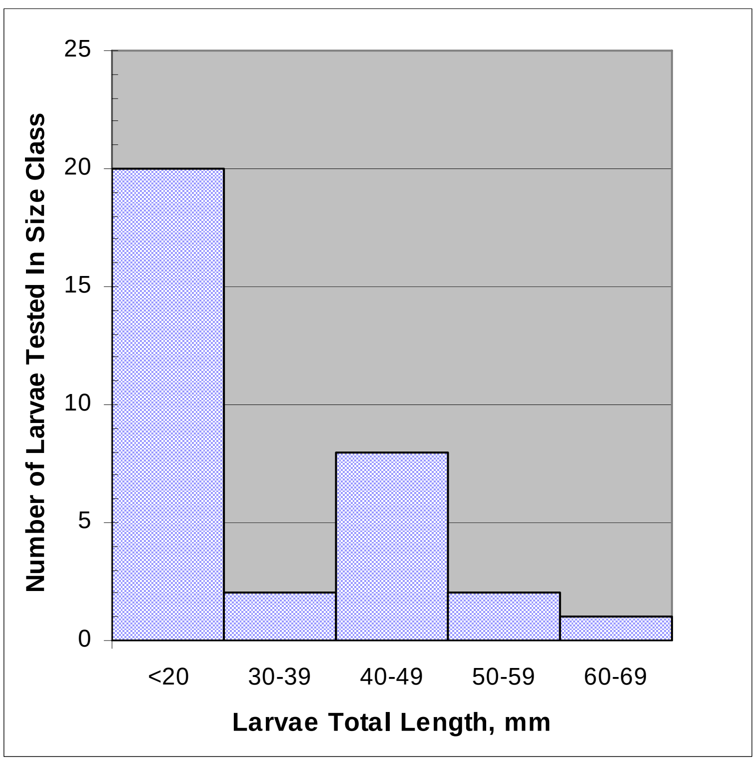


Figure 7 – Size distribution of pallid sturgeon larvae used in fish screen impingement survival tests.

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		

Table 1 – Screen Impingement Survival test data

Results - Screening Effectiveness based on NOAA Salmonid Fry Criteria

Tests of screening effectiveness based on NOAA salmonid fry criteria were only conducted with the third group of sturgeon larvae. A series of four test runs and two controls were initially conducted to observe fish behavior in the test flume (Table 2-3A). Fish were released 4.6 m upstream of the screen at mid-channel.

Following release from the insertion tube, all fish swam actively into the flow. The time required for flow to travel the length of the screen was ~ 7.2 sec. The average time for sturgeon larvae to pass the screen was 9.0 sec. The small difference in travel times indicates the larvae used active swimming to largely maintain reotactic orientation and did not display a behavior to avoid downstream drift. Although characteristic of all fish tested, this behavior may be different in fish conditioned to flowing water for longer periods.

Five sets of screen effectiveness tests were conducted over a two month period during which fish were released with the insertion tube located five ft upstream and adjacent to the screen guide wall.   Water velocities measured three inches in front of the screen at mid-depth are given in figure 7. 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 36mm to 60 mm TL. Average time required for fish to pass the length of the screen was 8.4 sec. All fish in the test set 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 trials and 11 controls. Number of test and control fish by size class is given in figure 8. The number of test fish and control fish in each size class chosen for the study were random. The number of fish in each size class typically represented approximately 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 the control groups.

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

Date	Series/Test Set	Fish #	Length	Mortality		No. of screen	Time to pass screen	
	3/F		mm	24 hr	48 hr	touches	sec	Comments
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			

Table 2 continued – Screening effectiveness test data

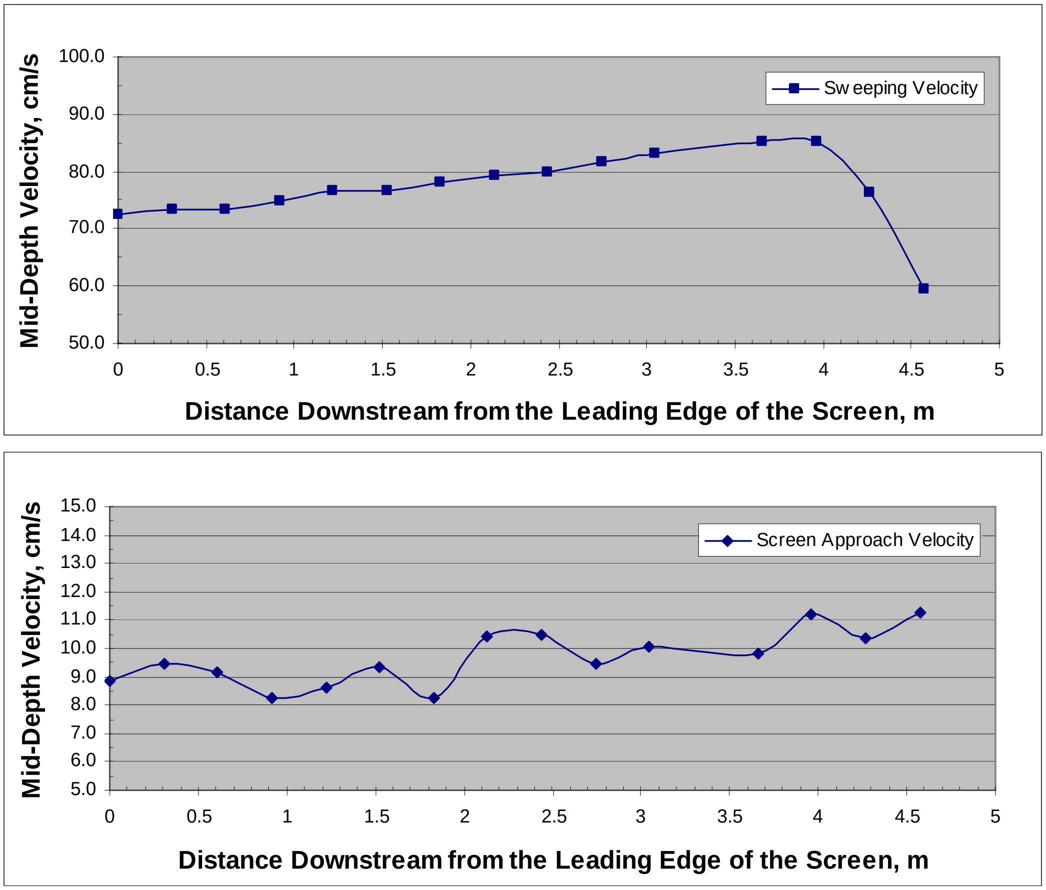


Figure 8 – Fish screen sweeping and approach flow velocities measured three inches in front of the fish screen.

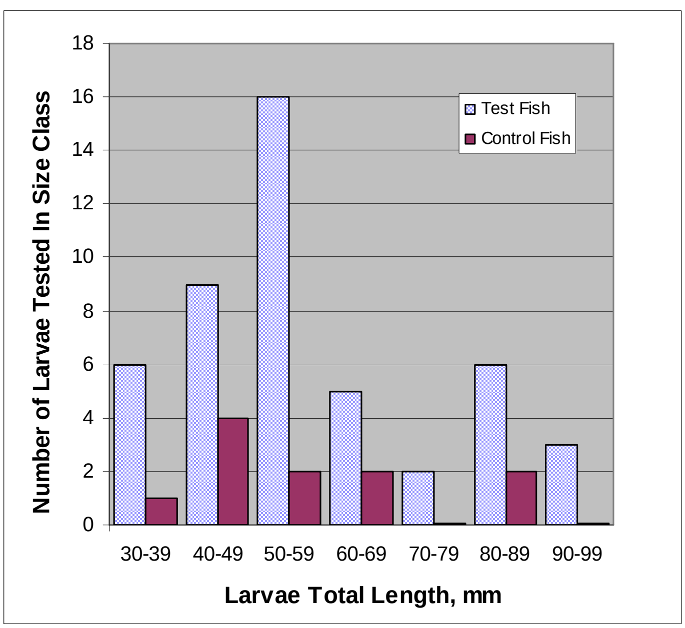


Figure 9 - Size distribution of pallid sturgeon larvae used in fish screening effectiveness tests.

Results - Recovery of Screen Impinged Larvae

Tests of recovery survival of impinged fish using a traveling screen was conducted using sub-20 mm larvae (group 1 fish) and larvae > about 30 mm (group 3 fish). Six trials of sub-15 mm larvae were conducted. All test larvae passed through the traveling screen and were not recovered. By observation, the larvae passed easily through the screen material without impinging. Twenty-six trials were conducted of larvae > 30 mm TL. The size distribution of test fish is given in figure 9. Fish handling, holding and test dates were similar for subtopics 3 and 4, therefore the same control group was applied to both test programs. During the first set of group 3 fish trails, nine fish were impinged on the traveling screen. Four larvae after passing over the traveling screen failed to be washed into the collection facility due to insufficient spray wash. These fish were not included in the test results. The impingement recovery system was corrected by increasing the discharge from the spray wash system.

Six tests were conducted using a screen speed of 81 cm/min and 64 cm of screen extending above the water surface. The screen travel time from the water surface to the spray wash recovery located on the top of the screen was 0.74 minutes. Larvae used in the test ranged from 38 mm to 60 mm TL. Fish impinged on the screen generally laid still on the screen as they were carried above the water surface (Fig. 10). Fish that remained relatively still were easily carried up the 30 degree inclined screen. No immediate mortalities occurred and all fish survived the 48 hour observation period. 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 at the top. The average test fish out-of-water-time (water surface to passing over the screen) was 1.63 minutes. The minimum and maximum times were 0.74 minutes and 3.0 minutes, respectively.

A second set of tests was conducted with the screen travel speed increased to 1.22 m/min. The faster screen travel reduced the above water screen travel time to 30 seconds. Tests were limited to three fish (58 mm, 60 mm and 78 mm TL) to evaluate if the shorter out-of water duration reduced fall back as the larvae traveled up the screen face. All fish were recovered with no immediate mortalities and no mortalities occurred during the 48 hr observation period. The average out-of-water period was 85 seconds with all fish falling back at least once.

Nearly all fish in first two test sets displayed a behavior of resting still on the screen for about 20 seconds after being carried above the water surface. Based on this observation, the water depth on the screen was increased from 0.76 m to 0.96 m to reduce the time from the water surface to the recovery spray wash to about 18 seconds. The screen speed was maintained at 1.22 m/min. Twelve fish were tested ranging in size from 45 mm to 77 mm (Table 3-4C). 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. Out-of-water recovery times averaged 19.5 seconds for the test group.

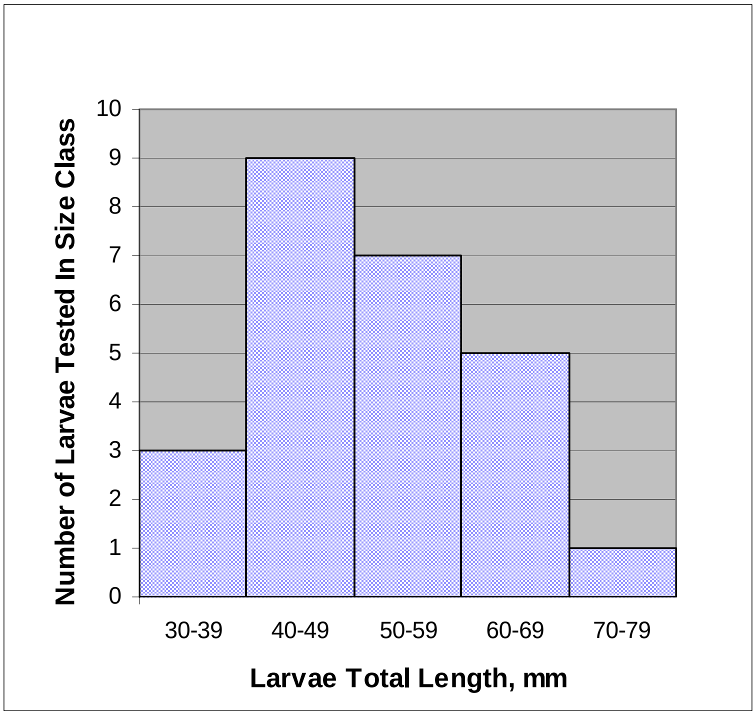
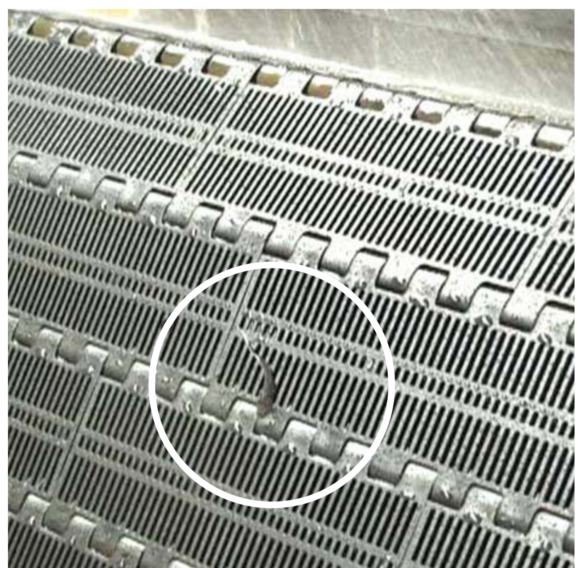


Figure 10 - Size distribution of pallid sturgeon larvae used in fish screen impingement recovery tests.

Larval pallid sturgeon impinged on fish screen below water surface.



Larval pallid sturgeon lying on fish screen above water surface.

Figure 11 – Photograph of pallid sturgeon larvae impinged on traveling fish screen (left). Photograph on the right shows larvae being lifted on the screen above the water. Spray wash at top of screen flushes larvae into recovery trough.

Date	Test subtopic/set	Fish #	Length TL	Mortality		Fish Impinged	Time above water surface	Number of fall backs	Screen speed 81 cm/min@20	Length of screen above water surface, cm	Screen travel time from water surface to	Comments
	4/A		mm	24 hr	48 hr		sec		122 cm/min@30		spraywash, min	Ave. Screen Approach Velocity = 12 cm/s
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											

Table 3 – Recovery of screen impinged larvae test data

ANALYSIS

Screen Impingement Survival-

The tests resulted in 100 percent survival for all time periods tested for fish larger than 30 mm TL. Sub-20 mm tests resulting in fish passing through the screen contained some mortalities in both the test and control groups. 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 control 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 (Fig 12). In the study, only about 2% of the variation in the data can be accounted for by a linear relationship with length. Over the range of lengths tested, we found approximately a factor of two improvement in swimming strength. 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.

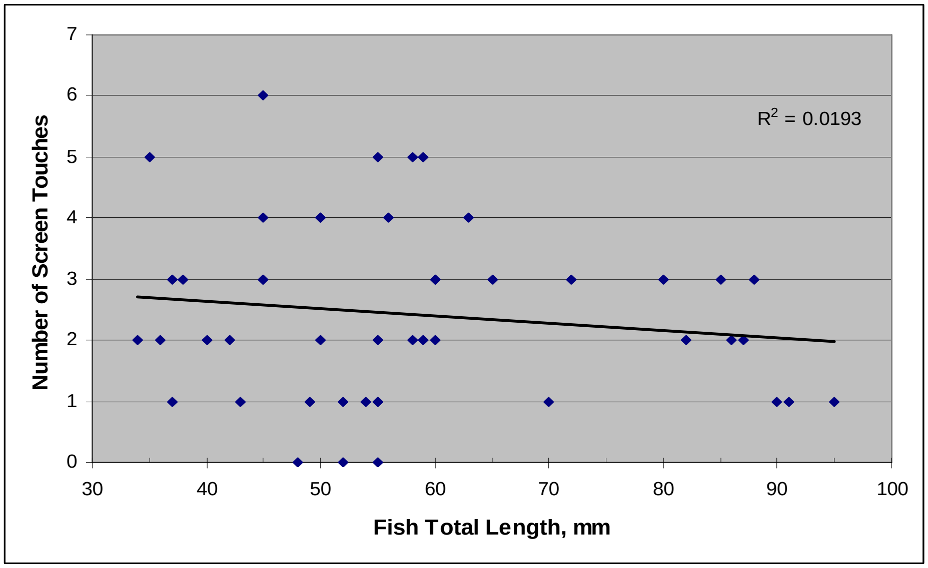


Figure 12 –Linear regression of fish length versus number of screen touches during a test run.

Larval Salvage by Direct Impingement Recovery

The tests resulted in 100 percent survival for all fish recovered larger than 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 (Fig 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. This suggests fish length for the 30 mm to 90 mm life stage does not alter the behavior of the fish during the impingement recovery process evaluated.

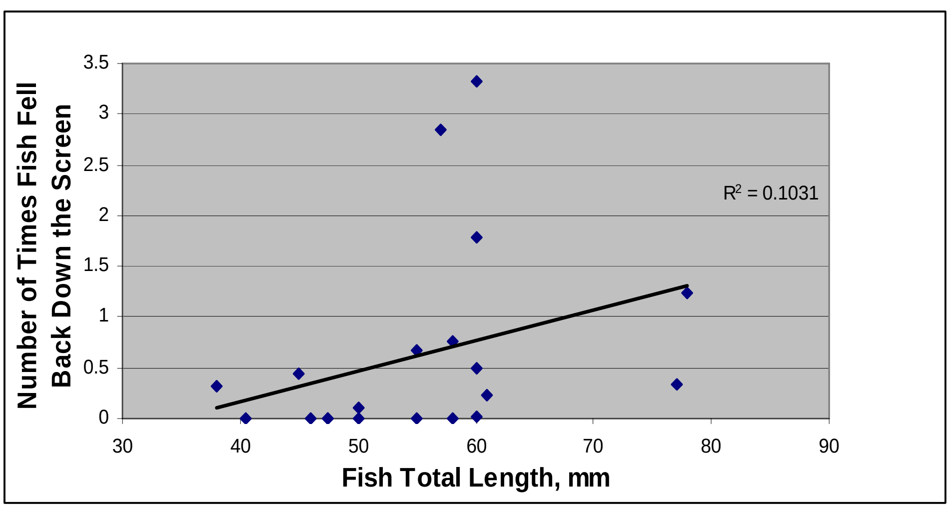


Figure 13 - Linear regression of fish length versus number of times a fish fell back down the traveling fish screen.

CONCLUSIONS

Sub-20 mm pallid larvae possess little reotactal swimming ability. These larvae drift with the current and are very susceptible to entrainment in flow diversions. Tests of fish screens designed to meet NOAA salmonid fry criteria were found to be ineffective at preventing diversion entrainment for the sub-20mm life stage. Test larvae < 18mm TL were found to pass easily through wedgewire screen with 1.75 mm wide slot openings. No direct relationship between mortality and passage through the screen was found in the study for sub-18 mm fish. Screening sub-20 mm pallid larvae with a primary screen is likely not practical. The study results do suggest larvae could tolerate secondary screening with fine mesh screens or nets located downstream of a primary screen. Fish > 30 mm TL impinged on a fish screen for 10 minutes before being recovered by backwashing the screen showed no relationship to fish mortality. 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.

Fish larger than ~45 mm TL displayed sufficient swimming endurance to avoid impingement on fish screens designed for a 12 cm/s approach flow velocity and 60 second exposure. Study results indicated swimming endurances in excess of 300 seconds. Fish > 30 mm TL released adjacent to a NOAA design fish screen commonly tail touched the screen multiple times during passage. The study found no relationship between screen touches and fish mortality, or screen touches and fish length for the size classes tested.

Fish impinged on a Hydrostal 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 laid still on the screen for ~ 20 seconds following dewatering. The study showed no impact on fish mortality associated with the recovery process studied.

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