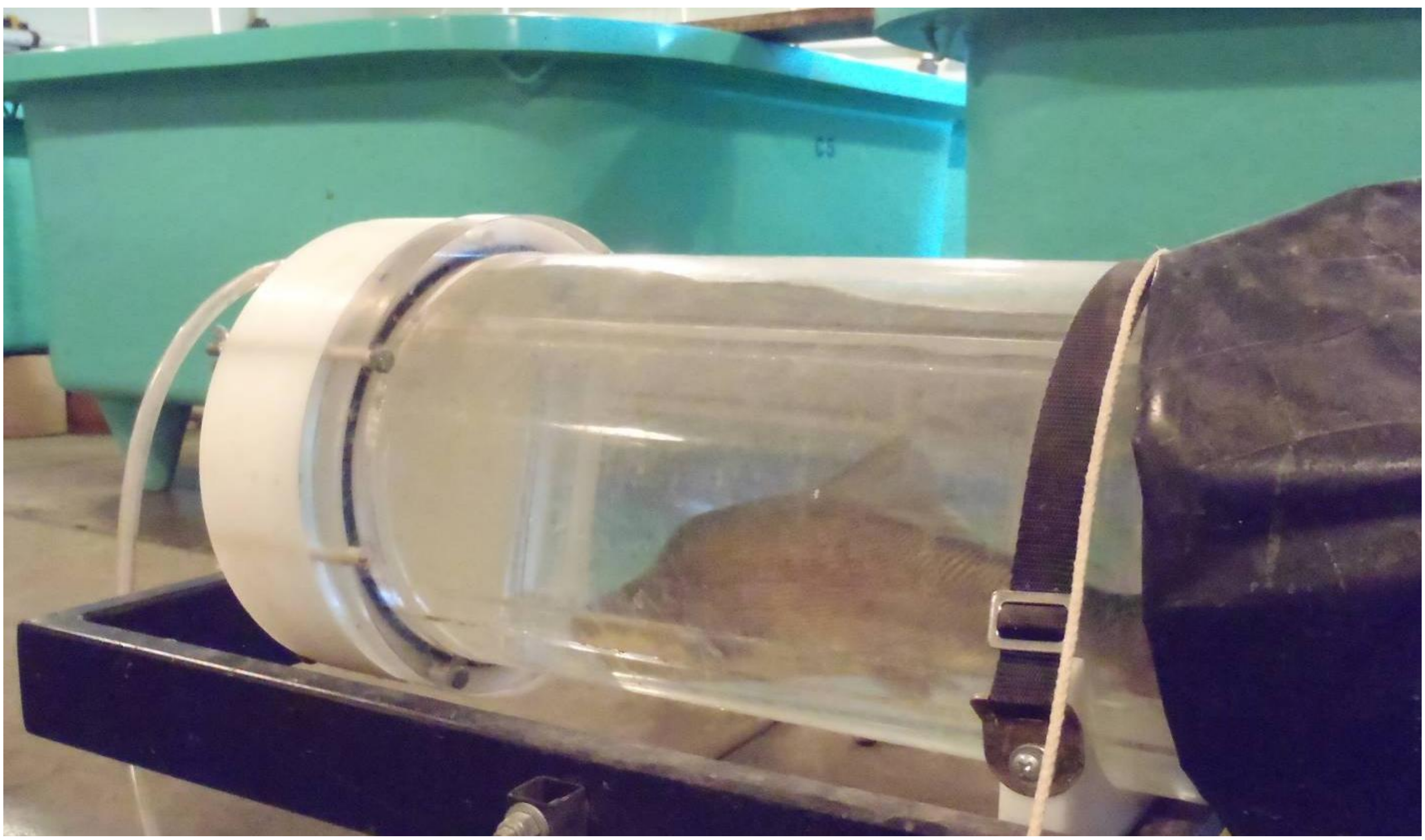
Lower Colorado River
Multi-Species Conservation Program

Balancing Resource Use and Conservation

Evaluation of Flow Conditioning Razorback Sucker in Flow-Through Raceways at Lake Mead Hatchery



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September 2011

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Lower Colorado River Multi-Species Conservation Program

Evaluation of Flow Conditioning Razorback Sucker in Flow-Through Raceways at Lake Mead Hatchery

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ACRONYMS AND ABBREVIATIONS

cm	centimeter(s)
cm/s	centimeters per second
f/kg	fish per kilogram
hrs/day	hours per day
kg	kilogram(s)
lb	pound(s)
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
m	meter(s)
mm	millimeter(s)
PVC	polyvinyl chloride
Reclamation	Bureau of Reclamation
T&E Room	Threatened and Endangered Room
TL	total length
TR	treatment

Symbols

°C	degrees Celsius
%	percent

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INTRODUCTION

Fish hatchery program facilities have long operated under a put-and-take methodology, with fish production and economic efficiency driving the methods of fish culture operations. These facilities have been primarily focused on rearing as many sport fish as possible for as little cost as possible. The goals of these hatcheries are to stock sport fish in local waters for recreational anglers to immediately harvest. In these put-and-take programs, long-term post-stocking survivability is not the primary focus. As hatchery programs have changed over the years, so have the species being reared and stocked. Federal and State agencies aimed at conserving threatened and endangered species are utilizing hatcheries in their repatriation programs in efforts to augment natural populations. The Bureau of Reclamation's (Reclamation) Lower Colorado River Multi-Species Conservation Program (LCR MSCP) has been, and is currently employing, repatriation as a management tool in the ongoing conservation efforts of endangered species (Kegerries and Albrecht 2009).

Razorback suckers (*Xyrauchen texanus*) are currently being raised in several hatcheries and are used for repatriation programs in the Lower Colorado River Basin. Unfortunately, razorback suckers have demonstrated poor post-stocking survivability (Mueller 2003; Schooley and Marsh 2007). Predation by non-native fishes, alteration of natural habitat, and overall poor fitness of captive reared razorback suckers are widely considered the main causes for such low survival rates (Marsh and Brooks 1989; Mueller 2003; Schooley and Marsh 2007). Addressing these elements has increasingly become an interest of the LCR MSCP. Increasing the target size of stocked fish has been a popular method for decreasing predation of stocked fish. These larger target sizes make it more difficult for gape-limited predators to consume repatriated fish. While increasing the target size has been beneficial, long-term post-stocking survivability remains low. Recent research interest has been geared towards investigating the condition and fitness of hatchery-reared fish.

Husbandry practices in hatchery environments do not replicate conditions in the wild (Wiley et al. 1993). Fish reared in hatcheries are provided ample food, do not experience variable seasonal flows, and are not exposed to predators. Poor physically and socially conditioned razorback suckers succumb more readily to predation by non-native predators and are more prone to downstream dispersal soon after stocking (Avery unpublished; Mueller 2003; Ward and Hilwig 2004). More research is needed to test different methods of enrichment during the captive rearing of razorback suckers that would increase post-stocking survival rates. Razorback suckers are generally reared in standing water systems or grow-out ponds (Ward et al. 2007). These fish are not exposed to flowing water conditions and any exercise benefits gained by such conditions. Previous studies have shown that razorback suckers benefit from exposure to flowing water conditions (Avery unpublished; Mueller et al. 2007).

Kegerries and Albrecht (2009) conducted a literature review to map out areas of focus for flow conditioning trials. Based on their literature review and objectives outlined in LCR MSCP Work Task C-26 "*Evaluation of Raceway Rearing of Razorback Sucker at Lake Mead Fish Hatchery,*" we conducted a series of trials testing different methods of flow conditioning in flow-through raceways. We designed flow-through raceways and rearing protocols for flow conditioning razorback suckers and evaluated how it affected swimming stamina, growth, food conversion efficiency, foraging ability, and the ability to treat diseases. Activities presented in this report accomplished the objectives of LCR MSCP Work Task C-26 for the LCR MSCP Fish Augmentation and Species Research Program (LCR MSCP 2006).

METHODS

The trials were conducted at the Lake Mead State Fish Hatchery. This facility is owned and operated by the Nevada Department of Wildlife and located within the National Park Service's Lake Mead National Recreation Area. Razorback suckers used in these trials were reared onsite from when they were larvae. These larval razorback suckers were captured from Lakes Mead and Mohave and also obtained from Reclamation's Fish Laboratory in Boulder City, Nevada. These fish were from the 2007–09 year classes. The fish were previously PIT tagged while being reared in the Lake Mead Hatchery's Threatened and Endangered Room (T&E Room) prior to relocation into trial raceways.

Three trials were conducted during this study. The goal of the study was to develop and assess various flow conditioning strategies and not necessarily creating true replicates. The objective of the first trial was to test two different raceway designs to determine which design was more appropriate for future flow conditioning trials. The raceway designs used in the second and third trials were based on the results of the first trial. Duration of velocity exposure in Trials 2 and 3 was 12 and 18 hours per day (hrs/day), whereas the duration was only 12 hrs/day in Trial 1. Slight modifications were made to feeding strategies for our second and third trials. Raceway design, feeding methods, and water velocities were identical in Trials 2 and 3. However, temperatures differed between those two trials in order to evaluate how temperature affected razorback suckers during flow conditioning.

Trial Raceways

Trial 1 (Summer 2010)

Trials were conducted in three rectangular fiberglass raceways (8.2 meters [m] long, by 1.2 m wide, by 0.89 m deep) located outside. Each raceway had fresh water flowing into the head of the raceway. Screens were set at the end of each raceway in order to block fish from entering the overflow drains. An air compressor powered multiple aeration stones that were placed throughout each raceway. The outdoor area was covered by an open canopy roof, which was installed during construction of the hatchery. Mesh bird net (3.2 centimeters [cm] x 3.8 cm) was hung around the perimeter of the canopy to deter local blue herons (*Ardea herodias*) that arrived shortly after fish were relocated to the outdoor raceways.

The two treatment raceways were customized in order to produce the desired water velocities. Both raceways were divided down the middle by cinder blocks, but were left open at the front and end of the raceway to allow water to circulate throughout the raceway. This also allowed fish to move to either side of the cinder blocks. Flow rates in each treatment raceway were mainly produced by in-tank propeller pumps (model PAB4, 1/2-horsepower propeller pump). Each pump had a flow rate of 795 liters per minute. Drain pipes in both treatment raceways were lowered to 0.4 m. Lowering the drain pipes decreased the volume of water in the system, creating a higher velocity environment. Treatment 1 (TR 1) was the low/variable velocity treatment. Two pumps were set upright at the end of the raceway in front of the screens. The two pumps were connected to a polyvinyl chloride (PVC) manifold that ran the length of the raceway on each side (figure 1). Water was returned to the raceway through 12 PVC returns evenly spaced out the length of the raceway. This design produced variable velocities throughout the raceway. There were several small dead spots that had little to no measurable velocity. However, velocities where the water exited the 12 returns were much higher. This system allowed fish to access these small flow refuges, but in order to do so, they had to swim through the “jets” of water at each return. Treatment 2 (TR 2) represented the high-velocity treatment. Four pumps generated the velocities in TR 2. Two pumps were laid down horizontally in opposite corners of the raceway (figure 2). This created a counterclockwise flow pattern in the raceway. The gaps at each end of the raceway allowed water to flow freely around the cinder blocks.

Figure 1.—TR 1 raceway design utilizing PVC returns.

The control raceway was not modified. The drain pipes were not lowered, allowing the raceway to maintain its full water capacity. The raceway was not separated by cinder blocks, and no pumps were present. This raceway represented how razorback suckers are typically reared in raceways.

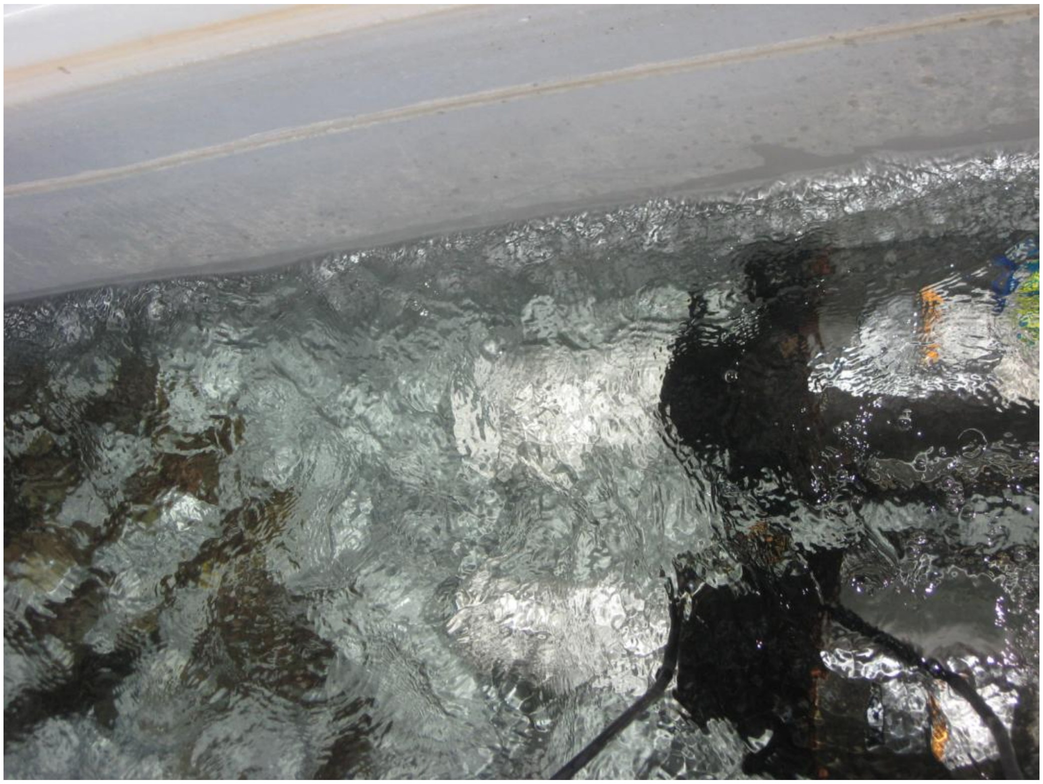

Figure 2.—Pumps laid down in opposite corners of the raceway for TR 2 of Trial 1. This configuration was used for all exercise treatment raceways in Trials 2 and 3.

Fish were moved into the outdoor raceways in March and April 2010. They were separated into their respective treatment raceways on May 21, 2010. The control and treatment raceways each held 374 razorback suckers. Prior to separation, random samples were taken to obtain pre-trial average total length (TL) and number of fish per kilogram (f/kg). Razorback suckers averaged 274 mm TL and 4.3 f/kg.

Trial 2 (Winter 2011)

Trial 2 was conducted in the same raceways as Trial 1. However, both treatments in Trial 2 utilized the four-pump laid down horizontally configuration that was used in TR 2 of Trial 1 (see figure 2).

Fish were moved into the outdoor raceways in December 2010. They were separated into their respective treatment raceways on December 30, 2010. The control and treatment raceways each held 312 razorback suckers. Razorback suckers averaged 221 mm TL and 8.2 f/kg.

Trial 3 (Summer 2011)

Severe winds destroyed the mesh bird net hanging around the outdoor raceways. We were forced to conduct Trial 3 inside the main building of the hatchery due to the continued presence of the local blue herons. Raceways used in this trial were identical to the dimensions of Trials 1 and 2. As in Trial 2, both treatments utilized the four-pump laid down horizontally configuration that was used in TR 2 of Trial 1 (see figure 2).

Fish were moved into the indoor raceways in March 2011. They were separated into their respective treatment raceways on June 10, 2011. The control and treatment raceways each held 225 razorback suckers. Razorback suckers averaged 249 mm TL and 5.5 f/kg.

Trial Regime

Trial 1

Pumps were plugged in, and the trial was initiated on May 25, 2010. The initial plan was to expose the fish to current 24 hrs/day. On June 1, 2010, fish in TR 2 began showing signs of disease. TR 2 was treated with salt (NaCl-Sodium Chloride, 12.5 parts per thousand) for 5 days. The disease in TR 2 progressed, and fish in TR 1 suddenly began showing similar signs. Pumps in both treatment raceways were turned off on June 7, 2010. Oxytetracycline was administered for 4 days at a dosage of 20 milligrams per liter. The fish were immersed for 1 hour a day during the 4-day treatment. During immersions, water flowing into the raceways was turned off, and two pumps were turned on for water circulation in the raceway. After the 4-day treatment, pumps remained off until the fish showed no signs of disease and normal feeding behavior resumed. To lower the stress level on the treatment fish, it was decided to shorten the duration of current. Pumps were on for 12 hours during the day and were off for the other 12 hours. This gave the fish time to rest at night. On June 21, 2010, the trials resumed with the new flow regimen. Fish were fed a commercially produced razorback sucker sinking pellet by hand at approximately 2 percent (%) body weight. Feed events occurred in the morning, midday, and early evening. All the raceways were cleaned weekly. The 30-day trial concluded on July 20, 2010.

Flows were measured using a Swoffer Model 2100 series open stream current velocity meter. Current velocity was measured prior to fish inhabiting the raceways and then monitored weekly throughout the duration of the trial. TR 1 had an average velocity of 23 centimeters per second (cm/s). The averge velocity in TR 2 was 36 cm/s. The control raceway produced velocities too low to measure. Water temperature at the beginning of the trial was 17 degrees Celsius (°C) and 27 °C at the end of the trial.

Trial 2

The trial was initiated on January 7, 2011. Pumps in TR 12H were on for 12 hrs/day and on for 18 hrs/day in TR 18H. [1] Fish were fed a commercially produced razorback sucker sinking pellet by 12-hour belt feeders at approximately 2 percent body weight. The 12-hour feed belt slowly dispensed feed over a 12-hour duration, beginning in the morning. All raceways were cleaned weekly. The 30-day trial concluded on February 5, 2011. TR 12H had an average velocity of 38 cm/s, and TR 18H averaged 39 cm/s. The water temperature at the beginning and end of the trial was 13 °C.

Trial 3

The trial was initiated on June 13, 2011. Pump duration, feeding methods, and water velocities were identical to Trial 2. The 30-day trial concluded on July 12, 2011. The water temperature at the beginning of the trial was 20 °C and 21 °C at the end of the trial.

Swim Chamber Testing

A swim chamber was used to test if there was a difference in swimming ability among unexercised (control) fish and exercised (treatment) fish (figure 3). Mueller (2003) and Avery (unpublished) both employed this same swim chamber for swimming performance testing. The swim chamber consisted of two Plexiglass tubes and a motor that powered a propeller. The tunnel where the fish swam was a smaller Plexiglass tube surrounded by a larger diameter Plexiglass tube. There was a removable cap at the head of the tunnel where the fish entered or exited the swim chamber. A propeller that created the current within the chamber was attached to an external motor at the other end of the swim chamber. Water velocities were adjusted by a variable speed motor controller. A screen was mounted in front of the propeller to protect fish from coming in contact with it. Aerated fresh water was continually pumped in through two nozzles at the motor end of the swim chamber, and excess water exited through a drain nozzle at the head of the chamber.

Subsamples from the control and treatment groups were randomly collected and moved to a temporary holding tank inside the T&E Room. Fish were individually drawn at random from the holding tank and placed in the swim chamber. Size frequencies for the subsampled fish ranged from 170–419mm TL (tables 1–3).”Each fish was acclimated in the swim chamber for 5 minutes

[1] TR 12H and TR 18H refer to the duration of velocity exposure (hours) in Trials 2 and 3. TR 12H had a 12-hour on/12-hour off cycle, and TR 18H had an 18-hour on/6-hour off cycle. The flow rates were the same for both of these treatments.

Figure 3.—Swim chamber used to measure failure velocities.

with no flow. Fish were then subjected to 12 cm/s, for 5 minutes, to acclimate to the flowing environment. Water velocities were then increased by 3 cm/s every 1 minute. This increase continued until the fish was unable to maintain its position in the tunnel. When the fish was unable to maintain its position and was pinned against the screen, this was determined to be its failure velocity. Failure velocity and TL were recorded after each test. Fish were then returned to their treatment raceway.

Table 1.—Frequencies of razorback sucker by size class in each subsample of Trial 1

Size class	Pre–trial	Control	TR 1	TR2
170–199	0	0	1	0
200–219	0	1	0	0
220–239	4	0	0	1
240–259	2	2	3	1
260–279	6	2	4	2
280–299	3	8	4	5
300–319	2	4	2	2
320–339	2	1	1	4
340–359	0	1	2	1
360–379	0	0	2	1
380–399	0	0	0	1
400–419	0	0	0	1

Table 2.—Frequencies of razorback sucker by size class in each subsample of Trial 2

Size class	Pre-trial	Control	TR 12H	TR 18H
170–189	0	1	1	3
190–209	4	5	2	1
210–229	8	5	6	5
230–249	7	5	6	4
250–269	1	4	3	5
270–289	0	0	2	2

Table 3.—Frequencies of razorback sucker by size class in each subsample of Trial 3

Size class	Pre-trial	Control	TR 12H	TR 18H
170–189	1	0	0	0
190–209	1	0	0	0
210–229	3	0	1	0
230–249	7	3	3	1
250–269	3	7	5	4
270–289	2	6	3	4
290–309	2	4	7	6
310–329	0	0	1	3
330–349	1	0	0	0
350–369	0	0	0	0
370–389	0	0	0	2

RESULTS

Trial 1

Swim Chamber Tests

The mean failure velocity for unexercised fish was 53.4 cm/s. TR 1 fish had a mean failure velocity of 61.1 cm/s (14% increase). Mean failure velocity for TR 1 fish was significantly higher than the unexercised fish (two-sample *t*-test: $P < 0.05$). The mean failure velocity for TR 2 fish was 81.6 cm/s (53 % increase) and significantly higher than unexercised fish (two-sample *t*-test: $P < 0.05$) (figure 4). TR 2 fish had a 34% higher mean failure velocity than TR 1 fish, which was significantly higher (two-sample *t*-test: $P < 0.05$). Mean failure velocities were significantly different among test groups (ANOVA: $F > F_{crit}$, P

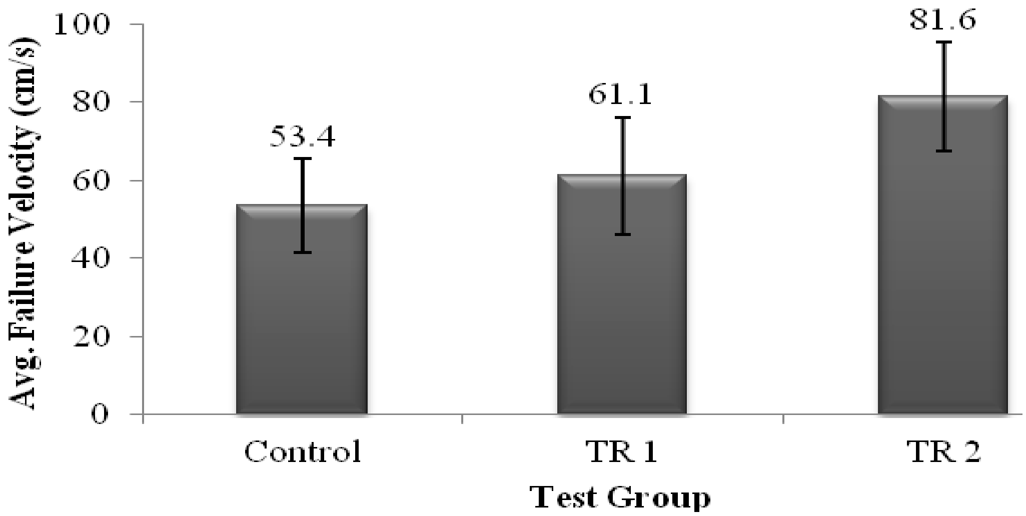

Figure 4.—Average failure velocities for Trial 1.

< 0.05). The TL did not have a strong correlation with failure velocity for unexercised, TR 1, or TR 2 fish ($r^2 = 0.0381$, $r^2 = 0.2356$, $r^2 = 0.4123$, respectively).

Growth and Food Conversion Efficiency

The unexercised fish gained 5.1 kilograms (kg) over the duration of the experiment (5% increase). Fish in TR 1 gained 10.2 kg (11% increase). TR 2 weight increased the most, gaining 47.8 kg (47% increase).

The mean TL for unexercised fish (289.7 millimeters [mm]) was 16.1 mm longer than the pre-trial mean TL of 273.6 mm (two sample *t*-test: $P < 0.05$). Fish in TR 1 (293.4 mm) grew 3.7 mm longer than the unexercised fish (two sample *t*-test: $P > 0.05$). The highest growth occurred in TR 2 (313.8 mm). TR 2 fish were 24.1 mm longer than the unexercised fish and grew significantly more than the unexercised and TR 1 fish (two sample *t*-test: $P < 0.05$ for both). Mean TL was not significantly different among test groups (ANOVA: $F < F_{crit}$, $P > 0.05$).

Food conversion rates are expressed as the pounds of feed fed for the fish to gain 1 pound (lb). Fish culturists typically calculate and report these rates in lbs instead of the metric kg. The unexercised fish and TR 1 fish had food conversion rates of 16.1 and 8.0, respectively. TR 2 fish had a food conversion rate of 1.7, which was the most efficient among the three test groups (table 4).

Table 4.—Summary of results from Trial 1

	Pre-trial	Control	TR 1	TR 2
Fish/lb	1.9	1.8	1.7	1.2
Food conversion rate		16.1	8.0	1.7
Mean failure velocity (cm/s)		53.4	61.1	81.6
Mean TL	273.6	289.7	293.4	313.8
TL growth (mm/day)		0.54	0.66	1.3
% weight increase		5.7	11	53.5
% TL increase		5.9	7.2	14.7

Trial 2

Swim Chamber Tests

The mean failure velocity for unexercised fish was 47.0 cm/s. TR 12H fish had a mean failure velocity of 55.8 cm/s (18.8% increase). Mean failure velocity for TR 12H fish was significantly higher than the unexercised fish (two-sample *t*-test: $P < 0.05$). The mean failure velocity for TR 18H fish was 57.2 cm/s (21.7 % increase) and significantly higher than unexercised fish (two-sample *t*-test: $P < 0.05$) (figure 5). TR 18H fish had a 2.5% higher mean failure velocity than TR 12H fish, which was not significantly higher (two-sample *t*-test: $P > 0.05$). Mean failure velocities were significantly different among test groups (ANOVA: $F > F_{crit}$, $P < 0.05$). The TL did not have a strong correlation with failure velocity for unexercised, TR 12H, or TR 18H fish ($r^2 = 0.2618$, $r^2 = 0.2678$, $r^2 = 0.3183$, respectively) (figure 5).

Growth and Food Conversion Efficiency

The unexercised fish gained 3.7 kg over the duration of the experiment (9.7% increase). Fish in TR 12H gained 7.8 kg (20.4% increase). TR 18H weight increased the most, gaining 9.1 kg (23.8% increase).

The mean TL for unexercised fish (226.5 mm) was 5.5 mm longer than the pre-trial mean TL of 221 mm (two sample *t*-test: $P > 0.05$). Fish in TR 12H (231.8 mm) grew 5.3 mm longer than the unexercised fish (two sample *t*-test: $P > 0.05$). The highest growth occurred in TR 18H (232.4 mm). TR 18H fish were 5.9 mm longer than the unexercised fish, but did not grow significantly more than the unexercised and TR 12H fish (two sample *t*-test: $P > 0.05$ for both). Mean TL was not significantly different among test groups (ANOVA: $F < F_{crit}$, $P > 0.05$).

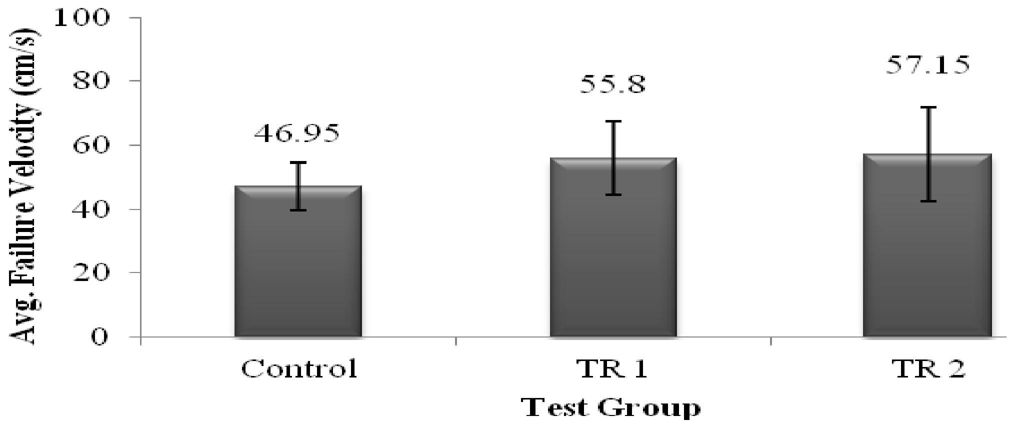

Figure 5.—Average failure velocities for Trial 2.

Food conversion rates are expressed as the pounds of feed fed for the fish to gain 1 lb. The unexercised fish and TR 12H fish had food conversion rates of 6.2 and 3.0, respectively. TR 18H fish had a food conversion rate of 2.5, which was the most efficient among the three test groups (table 5).

Table 5.—Summary of results from Trial 2

	Pre-trial	Control	TR 12H	TR 18H
Fish/lb	3.7	3.4	3.1	3.0
Food conversion rate		6.3	3.0	2.5
Mean failure velocity (cm/s)		46.7	55.8	57.2
Mean TL	221.0	226.5	231.8	232.4
TL growth (mm/day)		0.18	0.36	0.38
% weight increase		9.7	20.3	23.7
% TL increase		2.5	4.9	5.2

Trial 3

Swim Chamber Tests

The mean failure velocity for unexercised fish was 57.5 cm/s. TR 12H fish had a mean failure velocity of 79.7 cm/s (38.6% increase). Mean failure velocity for TR 12H fish was significantly higher than the unexercised fish (two-sample *t*-test: $P < 0.05$). The mean failure velocity for TR 18H fish was 83.1 cm/s (44.5 % increase) and significantly higher than unexercised fish (two-sample *t*-test: $P < 0.05$) (figure 6). TR 18H fish had a 4.2% higher mean failure velocity than TR 12H fish, which was not significantly higher (two-sample *t*-test:

$P > 0.05$). Mean failure velocities were significantly different among test groups (ANOVA: $F > F_{crit}$, $P < 0.05$). The TL did not have a strong correlation with failure velocity for unexercised, TR 12H, or TR 18H fish (r^2 = 0..1152, r^2 = 0.6294, r^2 = 0.3971, respectively).

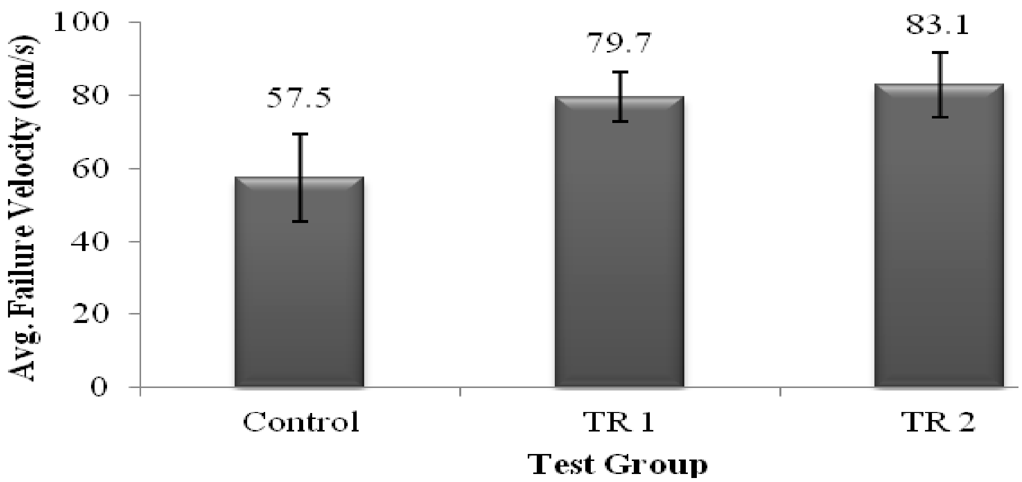

Figure 6.—Average failure velocities for Trial 3.

Growth and Food Conversion Efficiency

The unexercised fish gained 8.7 kg over the duration of the experiment (21.3% increase). Fish in TR 12H gained 19.6 kg (48.2% increase). TR 18H weight increased the most, gaining 31.8 kg (77.9% increase).

The mean TL for unexercised fish (268.9 mm) was 19.5 mm longer than the pre-trial mean TL of 249.4 mm (two sample *t*-test: $P < 0.05$). Fish in TR 12H (275.3 mm) grew 6.4 mm longer than the unexercised fish (two sample *t*-test: $P > 0.05$). The highest growth occurred in TR 18H (294.2 mm). TR 18H fish were 25.3 mm longer than the unexercised fish and grew significantly more than the unexercised and TR 12H fish (two sample *t*-test: $P < 0.05$ for both). Mean TL was significantly different among test groups (ANOVA: $F > F_{crit}$, $P < 0.05$).

Food conversion rates are expressed as the pounds of feed fed for the fish to gain 1 lb. The unexercised fish and TR 12H fish had food conversion rates of 2.4 and 1.0, respectively. TR 18H fish had a food conversion rate of 0.7, which was the most efficient among the three test groups (table 6).

Table 6.—Summary of results from Trial 3

	Pre-trial	Control	TR 12H	TR 18H
Fish/lb	2.5	2.1	1.7	1.4
Food conversion rate		2.4	1.0	0.7
Mean failure velocity (cm/s)		57.5	79.7	83.1
Mean TL	249.4	268.9	275.3	294.2
TL growth (mm/day)		0.6	0.9	1.5
% weight increase		21.3	48.1	77.8
% TL increase		7.6	10.4	1.5

DISCUSSION

The goal of this study was to construct flow-through raceways suitable for flow conditioning razorback suckers and evaluate various rearing strategies that could be employed prior to releasing captive reared razorback suckers in the wild. The practice of flow conditioning razorback suckers is relatively new, and there is little information available regarding design and rearing protocols. Testing different strategies provided the opportunity to observe and assess how each method impacted razorback suckers.

Swimming performance, growth, and food conversion efficiency were highest among fish exposed to flowing water conditions in all three trials. Furthermore, fish in the highest water velocity treatments (TR 2 and TR 18H) performed better in each category tested. The unexercised fish exhibited poorer swimming ability, food conversion efficiency, and growth among the test groups in all three trials. These traits of unexercised fish have been reported among researchers and may in part contribute to low post-stocking survivability in repatriation programs (Wiley et al. 1993; Brown and Laland 2001; Mueller 2003; Ward and Hilwig 2004).

Raceway Design

Fish reared in TR 2 of Trial 1 had a 34% higher mean failure velocity than fish in TR 1. As previously described, TR 1 was the low/variable velocity treatment utilizing a PVC return apparatus, and TR 2 had four pumps laid down horizontally in opposite corners. The design in TR 1 proved to have flaws. The PVC design formed several dead spots throughout the raceway and created lower velocities. However, points where water exited the PVC returns were much higher than areas where there were no returns. This gave fish the opportunity to find these dead spots and not exert much energy maintaining their position in the water column.

While observing fish in TR 2, it was obvious these fish constantly exerted energy. The water flowed counterclockwise around the cinder blocks, causing concern that the fish would just go with the flow and continuously lap around the blocks. This concern was immediately diminished when the pumps were turned on. Fish faced upstream on each side of the cinder blocks. The current in this setup was strong enough that the fish had to constantly swim to maintain their position. There were no dead spots in this system, and the fish were forced to swim everywhere in the tank. Another interesting note is that TR 1 and TR 2 kept cleaner than the control raceway. The current helped keep debris from settling on the bottom. During weekly cleanings, the control raceway was the only one to have extra feed remaining on the bottom of the raceway.

TR 2 of Trial 1 resulted in improved swimming ability, growth, and food conversion efficiency. These results suggested this was the better design for flow conditioning, so we used this setup as the basis for Trials 2 and 3. Trial 1 was conducted in the summer when warm water conditions favor growth and basic metabolic activities. Trials 2 and 3 were conducted in the winter and summer to test what effect water temperature has on flow conditioning razorback suckers and to determine what time of year would be more suitable for fish culturists to conduct pre-release flow conditioning efforts. Ward et al. (2004) found that colder water decreased the swimming ability of flannelmouth suckers (*Catostomus latipinnis*). Childs and Clarkson (1996) reported Colorado pikeminnow (*Ptychocheilus lucius*) also had decreased swimming performance in colder water. Like the razorback sucker, the flannelmouth sucker and Colorado pikeminnow are warm water species native to the Southwestern United States. Results from this study showed that cold water affected razorback suckers' swimming ability similar to the flannelmouth sucker and Colorado pikeminnow. Razorback suckers flow conditioned for 12 hrs/day in 20 °C water had a 43% higher mean failure velocity than when reared in 13 °C water and 45% higher mean failure velocity when flow conditioned for 18 hrs/day. Razorback suckers exposed to current for 18 hrs/day had a slight increase in mean failure velocity over the 12 hrs/day treatment. However, the 6-hour increase in velocity exposure did not significantly impact the difference in mean failure velocities ($P > 0.05$).

Growth and Food Conversion Efficiency

Fish culturists measure growth in terms of TL and weight. TL is often the most looked at measure of growth when rearing razorback suckers. In both warm water trials, razorback suckers reared in the four-pump laid down horizontally configuration grew significantly more in TL than the unexercised fish. Unexercised fish during this study grew on average 0.44 mm/day. On average, fish exercised for 12 hrs/day and 18 hrs/day grew 0.85 mm/day and 0.94 mm/day, respectively.

Most physiological and behavioral functions in fish are temperature dependent. Water temperature often has the most impact on growth rates in fish. Fish in Trial 2 (winter) had slower growth rates than fish in Trial 3 (summer). Fish exposed to flows for 12 hrs/day grew 2.5 times faster in the summer months. The 18 hrs/day fish grew 3.9 times faster in the summer months. Growth rates were 3.3 times slower for unexercised fish during the winter months.

Exercised fish exhibited more efficient food conversion rates in all three trials. Not only do captive reared razorback suckers grow faster during flow conditioning, but they also have higher feed conversion efficiencies. Other studies have shown similar results with exercised fish and improved feeding efficiency (Davison 1989 and 1997). Davison (1997) reported that fish that exercised consume more food. While exercised fish may consume more food, their bodies are essentially utilizing and metabolizing that food more efficiently and productively. It makes sense from all points of view to raise fish that have the most efficient food conversion rates.

Feeding Methods

Another focus of this study was to investigate alternative methods of food delivery and foraging behavior of razorback suckers during flow conditioning in flow-through raceways. In Trial 1, fish were fed by hand, and belt feeders were used in our second and third trials. When fed by hand in the four-pump laid down horizontally configuration, the feed was added directly in front of two pumps. The feed flowed downstream and continued to circle around the raceway. The fish had to actively capture the pellets. In the PVC design of Trial 1, fish had to actively capture pellets as well. However, some food would settle in dead spots for awhile before being flushed further downstream. In control raceways, feed immediately sank to the bottom, and fish would pick at the pellets at their leisure.

Belt feeders were employed for our second and third trials. Each belt feeder would dispense feed over a course of 12 hours. Each feeder was placed at the center of the raceway. Fish had to capture the feed as it flowed in the raceway. Belt feeders provide an advantage in they are less time consuming and spread the feed out throughout the day. Belt feeders resulted in better feed conversion efficiencies than feeding three times by hand.

There was no attempt to feed live or natural food in any of the trials. However, observations during feedings suggest that flowing water may improve the foraging ability of captive reared razorback suckers. Having to actively capture their food in captivity may increase their competitiveness and ability to find food in the wild.

Disease Treatment

Rearing fish in any captive environment puts added stress on fish. Hatcheries keep fish at higher densities than are found in any natural environment. High fish densities increase the bio-load of a system and, in turn, lower the water quality and create a stressful environment. Compounding that with increased water temperatures and handling, fish become stressed out very easily. When fish become too stressed, their immune system weakens and they become susceptible to illness. Disease treatment during flow conditioning is another area where information is limited.

Shortly after Trial 1 began and fish were moved to their respective treatment raceways, they contracted a disease. Upon examination, it was determined that they were infected with columnaris disease. Columnaris disease is a bacterial infection caused by the bacteria Flavobacterium columnare (Pulkkinen et al. 2010). Columnaris disease is common among production facilities rearing channel catfish (*Ictalurus punctatus*) and salmonids. Columnaris is often identified by cotton-like growths on fins and the head. If left untreated, it could spread to the gills and ultimately the bloodstream (Rach et al. 2008). The two treatment raceways were affected, but not the control raceway. This leads us to believe this was a stress-induced disease from being exposed to current for 24 hrs/day. After successful treatment of the disease, it was decided to lower the time exposed to current to 12 hours. The columnaris outbreak resulted in 11 mortalities in TR 1 and 31 mortalities in TR 2. These fish were not replaced during the trial, thus altering our treatment densities.

We did not experience any disease outbreaks in our second and third trials. This makes us think even more that the columnaris outbreak was attributed to 24 hrs/day exposure to current. The lack of rest may have been just too much for the fish to handle without much previous exercise. The disease outbreak showed us that disease treatment can be successfully applied during future flow conditioning treatments. However, our method of disease treatment interrupted the flow conditioning treatment. Flows were halted during medicated baths and then resumed when fish recovered. Nevertheless, future disease outbreaks can be avoided by less handling during warm temperatures and flow acclimation procedures.

CONCLUSIONS AND RECOMMENDATIONS

This study revealed that current and traditional methods of captive rearing razorback suckers may not be sufficiently preparing them for the wild environment. Methods of flow conditioning used in this study proved beneficial in improving swimming ability and growth of razorback suckers. Exercised fish were able to maintain body position at higher velocities than unexercised fish.

Improved swimming abilities and stamina may improve their ability to escape predation in the wild. These exercised fish could have a higher "burst" swim speed when encountered by a predatory fish and also have the stamina to endure a chase. It has also been shown that unexercised razorback suckers disperse further downstream upon stocking than exercised razorback suckers (Avery, unpublished). This ability to better navigate lotic systems would allow reintroductions into rivers and streams razorback sucker once inhabited. An enhanced ability for stocked fish to escape initial predation upon stocking should lead to higher post-stocking survival rates and increase the opportunity for long-term survival and wild recruitment in Lakes Mead and Mohave.

This study did not test what role flow conditioning has on predator avoidance. Studies have shown that exercised fish have increased predator avoidance skills compared to unexercised fish (Mueller et al. 2007). This could be attributed to an increase in physical conditioning of exercised fish. Brown and Laland (2001) and Mueller et al. (2007) suggest that predator naïve fish are unable to behave and respond appropriately when encountered by a predator in the wild. Predator avoidance and recognition is considered a learned social skill. Therefore, future studies should address "teaching" razorback suckers predator recognition and avoidance skills. Striped bass (*Morone saxatilis*) is the largest and most dangerous predatory fish in Lakes Mead and Mohave. Future studies should consider incorporating striped bass in predator avoidance training.

Conducting a study on post-stocking survival rates of exercised fish could be informative and could contribute to our understanding of what role flow conditioning might serve in the ongoing conservation efforts of razorback sucker. While conducting this type of study on large bodies of water the size of Lakes Mead and Mohave may be difficult, the knowledge gained by such a study could validate the effort. It remains unclear what the underlying factor is that leads to low survivability of repatriated razorback suckers. Multiple tracking studies of exercised fish might shed light on how flow conditioning affects post-release survival.

We envision using flow conditioning as a pre-stocking conditioning rearing method. Facilities currently rearing razorback suckers do an excellent job at producing adequate numbers of large and healthy razorback suckers. This type of flow conditioning could be employed 30 days prior to the stocking date, where fish would be moved into a raceway designed for flow conditioning and follow protocols similar to Trial 3.

During this study we addressed designs and implications of rearing razorback suckers in flowing water conditions. We found that flow conditioning using belt feeders, the four-pump laid down horizontally configuration, 18 hrs/day of current, and warm water conditions to be the most efficient and beneficial for flow conditioning razorback suckers. Thus, our results suggest that continued flow conditioning efforts be similar to this design. Fish culturists and biologists are looking for ways to produce higher quality fish, which would lead to increased post-release survivability. Rearing strategies used in this study could achieve that goal. Developing a stocking program for exercised razorback suckers, followed by post-stocking monitoring, would aid in the further evaluation of the benefits of flow conditioning. Incorporating a predator avoidance/recognition study of flow conditioned razorback suckers using predators encountered in Lakes Mead and Mohave would be beneficial.

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