LARVAL RAZORBACK SUCKER AND BONYTAIL SURVIVAL AND GROWTH IN THE PRESENCE OF NONNATIVE FISH IN THE STIRRUP FLOODPLAIN

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floodplain wetland, Green River, larval, razorback sucker, bonytail, nonnative fish, endangered species

EXECUTIVE SUMMARY

Despite successful reproduction by razorback suckers (*Xyrauchen texanus*) in the middle Green River, recruitment beyond the larval stage has not been recently observed. Bonytail (*Gila elegans*) are essentially extirpated in the wild and nearly all bonytail present in the Green River are hatchery-stocked fish. Floodplain wetlands may provide important rearing habitat for both larval razorback sucker and bonytail. However, survival of razorback suckers in restored floodplain habitat has not been observed since 1997, even when larvae were introduced directly into floodplain sites. Large nonnative fish populations in floodplain habitats have likely suppressed survival. The recent drought eliminated, or reset, nonnative fish populations in floodplain sites through complete dewatering. During an inundation period following a reset, initial nonnative fish densities are low. This study's goal was to test if introduced larval razorback sucker and bonytail could survive in the presence of reduced predation similar to that present in a reset wetland. Two densities of razorback sucker and bonytail larvae were tested using two 0.10 hectare enclosures with approximately equal numbers of nonnative fish. Survival in these enclosures was observed and estimated at 0.67% and 0.37% for razorback sucker in the low and high-density enclosures, and 1.7% and 1.3% for bonytail in the low and high-density enclosures, respectively. However, even at these low survival rates over 3,000 razorback suckers survived. Survival in the control enclosure (without nonnative fish) was 9.8% for razorback sucker and 17.1% for bonytail.

INTRODUCTION

Razorback sucker (*Xyrauchen texanus*) and bonytail (*Gila elegans*) are endangered species endemic to the Colorado River Basin. Razorback sucker were listed as endangered in 1991, and bonytail were listed as endangered in 1980. Wild bonytail are essentially extirpated from the Colorado River basin, with most fish currently in the wild consisting of hatchery reared and stocked fish. In the middle Green River however, there exists a small reproducing wild razorback sucker population. Despite successful reproduction, survival beyond the larval stage has rarely been observed (Muth et al. 1998). Lack of razorback sucker recruitment is attributed to habitat loss, and predation on larvae or early juveniles by nonnative fish (Minckley 1983; Minckely et al. 1991; Hawkins and Nesler 1991; Lentsch et al. 1996; USFWS 1996).

Floodplain wetlands are believed to be important habitat for survival and recruitment of razorback suckers (Wydoski and Wick 1998; Modde 1996 and Modde et al. 2001). In addition, recent studies of floodplain habitat in the lower Colorado River basin by Mueller et al. (2003) and historical photos presented by Quatarone (1993) suggest that floodplain habitats might also be important to bonytail. However, since the operation of Flaming Gorge Dam, the frequency of floodplain inundation has been reduced (Graf 1978; USFWS 1998; Flo-engineering 1997). As a result, access to floodplain habitats for endangered fish has been limited.

Despite intense sampling, razorback sucker survival in floodplain wetland sites was not observed during the Levee Removal Study (Birchell et al. 2002). An extremely small population of adult razorback suckers in the river, and the resulting low levels of spawning during the study, combined with large non-native fish populations, likely contributed to no observed larval survival. Modde et al. (1996) estimated the adult razorback sucker population in the middle Green River at only 500 fish when the study started, which has likely declined since (Bestgen et al. 2002).

Following the Levee Removal Study, Birchell and Christopherson (2004) continued assessment of juvenile and larval razorback sucker survival in floodplain wetland habitats. Hatchery produced age-1 and larval razorback suckers were introduced into floodplain sites during a two-year study to monitor growth and survival. Survival of age-1 juvenile razorback suckers during this study ranged between 56 and 72 percent. However, larval survival was not detected. High numbers of nonnative fish in the floodplain study sites likely suppressed larval razorback survival. The large numbers of nonnative fish were the result of multiple cohorts of nonnative fish that had reproduced in the floodplain sites over several years (Birchell et al. 2002).

Drought conditions in 2001 dewatered the floodplain sites and eliminated, or reset, nonnative fish populations. Nonnative fish numbers are expected to be lower in these same sites during the first inundation period following a reset because the only fish present entered from the river during surface water connection. Hypothetically, the best opportunity for larval native fish survival and eventual recruitment in floodplain habitats may occur the first year following a reset of the nonnative fish population. The objective of this study was to describe razorback sucker and bonytail survival and growth in the presence of known densities of nonnative fish in a reset floodplain wetland environment.

This report combines the results of two different studies. The Utah Division of Wildlife Resources (UDWR) had planned to use The Stirrup to conduct razorback sucker survival enclosure studies, and the Vernal, Fish and Wildlife Service (FWS) office had planned on using Old Charlie Wash for bonytail survival studies. River flows were not high enough to fill either site, prompting researchers to pump river water to artificially fill The Stirrup floodplain. The Vernal FWS decided to combine the bonytail with the razorback suckers in The Stirrup enclosures. Both projects were conducted independently. After the projects were completed the Program Director asked the researchers to combine the two projects into one report, this report.

This adds some confusion to the report because different population estimators were used, and more emphasis was placed on bonytail growth.

STUDY AREA

Enclosures designed to hold larval fish were constructed at The Stirrup floodplain wetland on the Green River (River Mile [RM] 276.0) near Vernal, Utah.

METHODS

Study site and enclosure design

During high river flows when the site inundates, The Stirrup ranges between 8.1 and 13.8 surface hectares at river flows of 13,000 ft^3/s (368 m^3/s) and 24,000 ft^3/s (680 m^3/s) respectively (USGS gage at Jensen). The Stirrup retains sufficient water throughout the year to support fish when peak river flows exceed 14,000 ft^3/s (396 m^3/s) for several weeks. However, peak flows have recently not exceeded 14,000 ft^3/s (396 m^3/s) and the site completely dried in 2001. In 2002, flows were again inadequate for natural inundation. Consequently, for this study, water was pumped into the site from the river. After one week of pumping, approximately 1.0 m of water depth was achieved. To maintain water level, pumping was reinitiated periodically during the remainder of the study.

Two, 22.9 m x 45.7 m (0.10 hectares) and one 4.9 m x 4.9 m enclosures were built at The Stirrup site in March and April 2002. The enclosures were essentially a steel post and wire fence, similar to a livestock pen. They were constructed with two-meter steel fence posts, with four layers of fencing material. The four layers were: a solid tarp that was impervious to all organisms, 0.1016 cm mesh window screen, 0.635 cm hardware cloth, and 4.88 m x 1.219 m heavy galvanized wire fence panels. The tarp layer was removed, as the fish grew large enough to be contained by the window screen. This allowed better circulation with water outside the enclosures.

Water Quality Measurements

Water temperature, pH, and dissolved oxygen were monitored over a 24 hour period for multiple days at approximately two week intervals between June 11 and August 6 with a Hydrolab minisonde. Measurements alternated every other day between each enclosure during the time period. A staff gage was placed at the deepest site in the high-density fish enclosure and checked every few days to monitor maximum depth in the enclosures. Zooplankton was sampled at one-week intervals between May 14 and July 15, 2002. Three samples each were taken from the high-density enclosure, low-density enclosure and outside the enclosures on each sampling date. The plankton net sampled an area of 0.07 m^2 and were 80 micron mesh size.

Fish stocking and sampling

Two densities of razorback sucker and bonytail larvae with approximately equal numbers of nonnative fish were tested (Table 1). The numbers of nonnative fish introduced were based on densities observed during the Levee Removal study (Birchell et al. 2002). Prior to breaching the levees for the Levee Removal study, the floodplain sites were dry and so the fish populations were reset. The fish assemblage, and relative density, that entered these reset floodplains during the first year of the Levee Removal study was used to test the reset theory in this study. The high-density enclosure (high for endangered fish larvae) was stocked with 81 fathead minnow (*Pimephales promelas*), 37 red shiner (*Notropis lutrensis*), 15 black bullhead (*Amierus melas*), 18 green sunfish (*Lepomis cyanellus*), and 3 carp (*Cyprinus carpio*) (154 fish) prior to introducing larval endangered fish. The low-density enclosure (low for endangered fish) received 75 fathead minnow, 42 red shiner, 16 black bullhead, 12 green sunfish and 4 carp (149 fish) also prior to introducing larval razorback (Table 1). The nonnative fish used in the experiment were collected from the Green River and local ponds, and they were of mixed age 1+.

Table 1. Summary of larval razorback sucker, bonytail, and nonnative fish quantities introduced into enclosures at The Stirrup floodplain wetland, Green River (RM 276.0) May 2002.

		Number introduced		
Species	Date	Low-density enclosure	High-density enclosure	Control
Razorback Sucker	May 14, 2002	5,788	0	1,000
	May 17, 2002	5,590	97,315	0
	May 23, 2002	48,995	128,794	0
	May 24, 2002	0	215,707	0
	May 29, 2002	0	15,377	0
Total RZ		60,373	457,193	1,000
Bonytail	May 8, 2002	21,250	71,500	5,250
Fathead Minnows	May 17-24, 2002 [a]	75	81	0
Red shiners	May 17-24, 2002	42	37	0
Black bullheads	May 17-24, 2002	16	15	0
Green sunfish	May 17-24, 2002	12	18	0
Carp	May 17-24, 2002	4	3	0
Total Non-native		149	154	0

[a] Most nonnative fish were introduced on May 17, 2002. However, there were six black bullheads and approximately 30 red shiners added to each enclosure on May 23, 2002. Twenty-five fathead minnows and 16 green sunfish were added to the high-density enclosure on May 21 and May 24, 2002 respectively.

The densities for razorback sucker and bonytail were higher than may be naturally expected, and were considered a positive control to evaluate if survival was possible at any density. Larval razorback sucker were obtained from the Ouray National Fish Hatchery. A total of 60,373 larval razorback suckers were introduced into the low-density enclosure and 457,193 into the high-density enclosure (Table 1). Only larval razorback sucker and bonytail were stocked into the small 24.28 m^2 enclosure. This small enclosure was used as a control to test larval razorback sucker and bonytail survival without nonnative fish present.

The study design was the same for the bonytail. It included two densities of bonytail (high and low-density) introduced into enclosures with approximately equal numbers of nonnative adults (Table 1). On May 8, 2002, approximately 71,500 bonytail larvae were introduced in the high-density enclosure and 21,250 larvae introduced into the low-density enclosure. An additional 5,250 larvae were introduced into the smaller control enclosure. Dexter National Fish Hatchery and Technology Center provided the bonytail larvae, which were introduced into the same enclosures with razorback sucker and thus experienced similar exposure to nonnative fish.

Fyke nets (0.32 cm and 0.64 cm mesh) were used for sampling outside enclosures. Only nets with 0.32 cm mesh were used inside the enclosures. On June 22, preliminary sampling was conducted to measure the growth of razorback sucker and bonytail. A 50-individual sub-sample was used. Sampling within enclosures occurred again in the first two weeks of August.

Inside the enclosures, nets were set in a star pattern, alternating between low and high-density sites for five days. Fish captured inside the enclosures were counted and released into the floodplain outside the enclosures. All nonnative fish captured were removed during sampling. Population estimates with 95% confidence limits for razorback suckers and nonnative fish inside the enclosures and nonnative fish outside enclosures, were calculated using depletion techniques. Depletion techniques were used inside the enclosure because the level of sampling was great enough to capture most of the fish. The number of bonytail in each enclosure was calculated using the removal estimator [M(bh)] from the computer software CAPTURE.

Intensive sampling for population estimation outside the enclosures occurred the last week of July. This was done to measure the level of escapement from the enclosures. Nets were set outside the enclosures for four consecutive days. Razorback suckers captured outside the enclosures were marked by removing the right pelvic fin. The main wetland outside the enclosures was sampled again on October 8, 2002. The razorback sucker population outside the enclosures was estimated using the Peterson, and the Schumacher and Eschmeyer methods described in Krebs (1999). Bonytail outside the enclosures were estimated using the Darrock estimator [M(t)] from the program CAPTURE. The control enclosure was seined repeatedly until all fish were removed.

An underwater video camera was used to record fish behavior, predator avoidance, and use of cover.

RESULTS

Water Quality Measurements

Spring flood flows peaked at 7,570 cfs, (214 m^3 /sec) far below the magnitude needed to connect the river to The Stirrup floodplain (~13,500 cfs or 283 m^3/sec). Due to low flow, river water was pumped into the floodplain from the river in late April and provided a maximum depth in excess of 1.0 meter within study enclosures. Following an initial drop in depth to 0.93 m in the fish enclosures, water elevation was increased to 1.06 m and maintained at approximately 1.0 m through the study. Water quality in the Stirrup was conducive to growth of age-0, warm water fish with recorded temperatures ranging from 19 to 28°C and averaging 25.4° C (Figure 1.).

Dissolved oxygen rarely dropped below 5.0 mg/l at any time of day during the study when data were collected (Figure 1.).

Zooplankton densities were dramatically influenced by the presence of fish. The zooplankton density in the floodplain outside the study enclosures showed a typical floodplain rapid increase up to 400 zooplankton per liter. This was followed by a subsequent decline to between 30 and 50 z/l following the appearance of vascular plants (Figure 2.). Zooplankton density outside the fish enclosures also showed a small but consistent increase mid summer, coincident with pumping activity to maintain water elevation. The spring zooplankton peak in both the high and low-density enclosures was dramatically lower with densities never exceeding 100 z/l in the spring. Whereas zooplankton densities were increasing outside the fish enclosures in early July, zooplankton densities within the fish enclosures continued to decline. In July, zooplankton densities averaged 7.6 z/l and 5.6 z/l in the high and low-density enclosures, respectively, but averaged 86.3 z/l outside the fish enclosures (Figure 2.). These zooplankton densities reflect the relatively few fish outside the enclosures as compared to inside the enclosures.

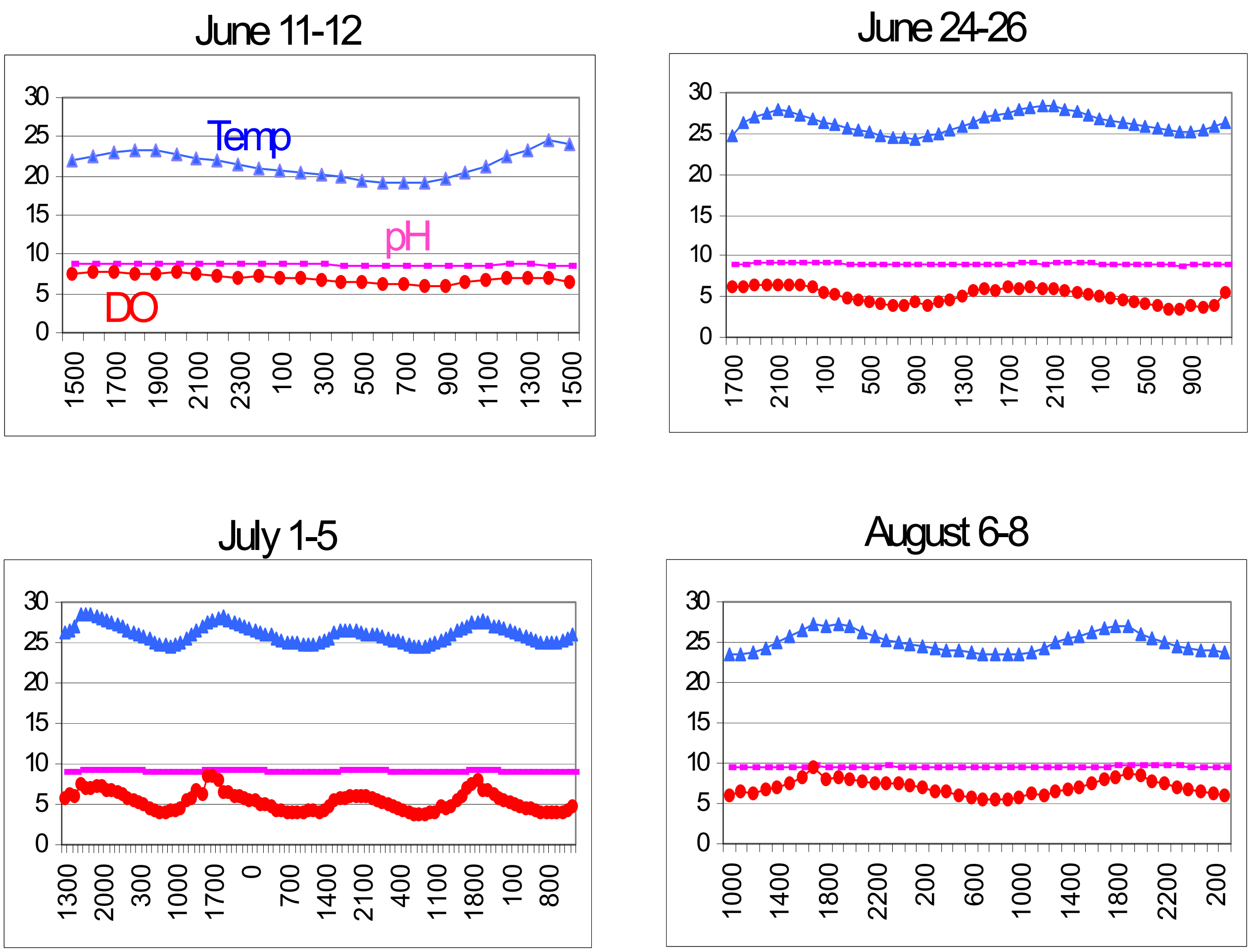

Figure 1. Water quality parameters measured in the Stirrup floodplain during the spring and summer of 2002. Blue triangle = temperature, purple line = pH, and red circles = dissolved oxygen.

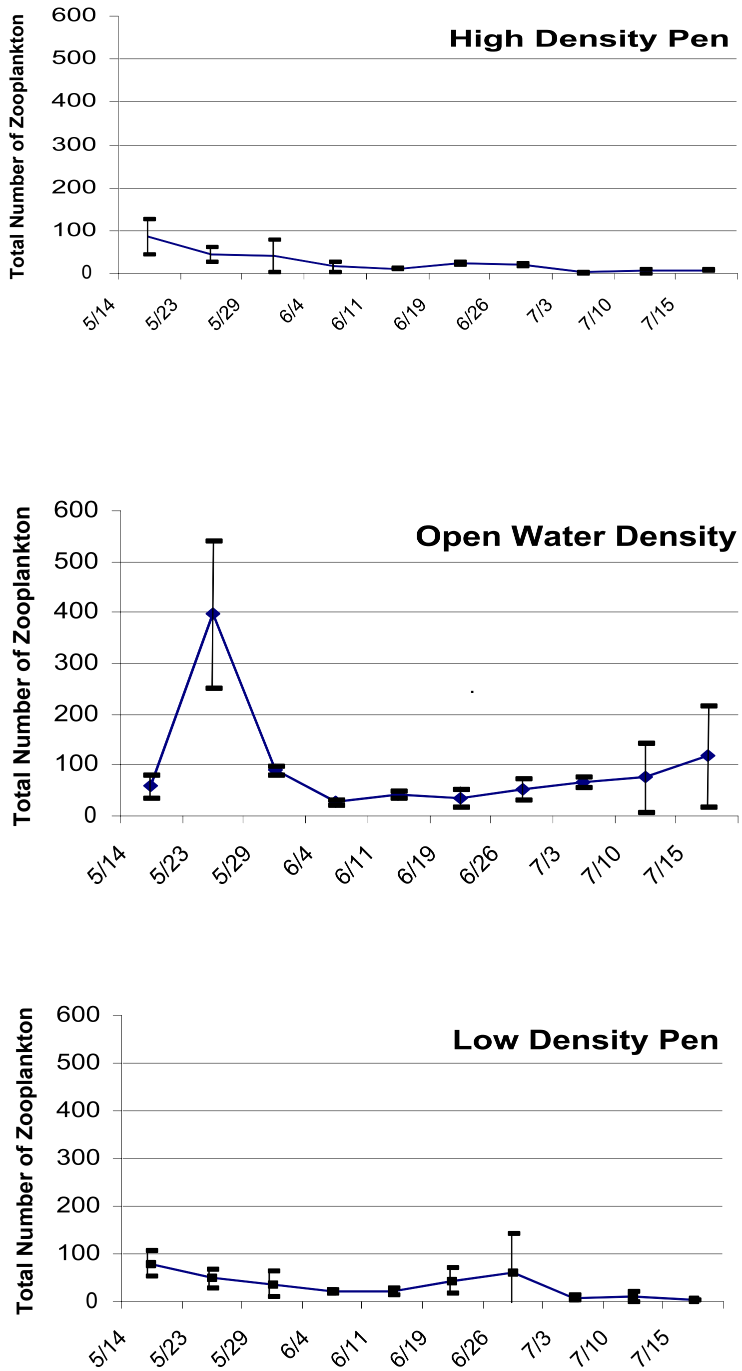

Figure 2.

Zooplankton densities per liter in high density and low-density enclosures and outside of enclosures in The Stirrup during the spring and summer of 2002 (vertical bars = plus and minus one standard deviation).

Razorback Sucker

Survival

On July 30, 2002, the area outside the enclosures was sampled to quantify the number of razorback suckers that escaped the enclosures. The Schumacher and Eschmeyer method produced an estimate of 1,113 fish with 95% confidence limits between 761 and 2,070 for razorback suckers that escaped the enclosures (Table 2).

Similar results were obtained using the Peterson method. The estimated population was 1,512 fish with 95% confidence limits between 917 and 3,547 fish (Table 2).

Table 2. Total razorback sucker population estimate for The Stirrup floodplain wetland, Green River (RM 276.0) in August 2002.

	Schumacher and Eschmeyer			Peterson		
	Nhat	Lower	Upper	Nhat	Lower	Upper
Outside enclosures	1,113	761	2,070	1,512	917	3,547
[a] High-density	1,586[c]	1,586	1,773	1,709[c]	1,709	1,896
[a] Low-density	319	276	445	402	359	528
[b] Control	98	n/a	n/a	98	n/a	n/a
Total	3,116	2,721	4,386	3,634	2,877	5,863

[a] Razorback sucker numbers used for this table are the population estimates with confidence limits for each enclosure. [b] Control population is not an estimate. It is the total number recovered. [c] Actual number offish captured was used for the population estimate.

From July 30 to August 13, 2002, the enclosures were repeatedly netted to establish depletion curves (Table 3 and Table 4).

In the low-density enclosure, the Peterson razorback sucker population estimate was 402 fish with 95% confidence limits between 359 and 528 fish (Table 2). Survival ranged from 0.62 to 0.87 percent (Table 5).

Table 3. Razorback sucker capture data for the low-density enclosure at The Stirrup floodplain wetland, Green River (RM 276.0) during each sampling period, July – August 2002.

Date	Number captured	Cumulative total
July 31, 2002	159	0
August 2, 2002	141	159
August 7, 2002	27	300
August 9, 2002	32	327
Total	359	

Table 4. Razorback sucker capture data for the high-density enclosure at The Stirrup floodplain wetland, Green River (RM 276.0) during each sampling period, July and August 2002.

Date	Number captured	Cumulative total
July 30, 2002	1,049	0
August 1, 2002	154	1,049
August 6, 2002	300	1,203
August 8, 2002	61	1,503
August 13, 2002	145	1,564
Total	1,709	

The estimated (Peterson) number of razorback suckers in the high-density enclosure was 1,709 fish. The 95% confidence limits were between 1,709 and 1,896 fish (Table 2). The Schumacher and Eschmeyer estimate for the high-density enclosure was 1,586 (Table 2). The 95% confidence limits were between 1,586 and 1,773. Survival ranged from 0.37 to 0.41 percent (Table 5).

A total of 98 razorback suckers were removed from the control enclosure that equates to a 9.8% survival rate. The control enclosure was very tight and escapement was likely not a factor. The survival reported was likely affected by the high density of larval fish in the control enclosure resulting in an outbreak of Ichthyophthiriasis.

Table 5. Larval razorback sucker survival estimates with 95% confidence limits for low-density, high-density and control enclosures at The Stirrup floodplain wetland, Green River (RM 276.0) July 30-August 13, 2002.

Enclosure	Survival Estimate	Lower Limit	Upper Limit
Low-density	0.67%	0.62%	0.87%
High-density	0.37%	0.37%	0.41%
Control	10.8%	NA[a]	NA[a]

[a] Confidence intervals not applicable because we assumed all fish were removed from the control enclosure.

Growth

Growth rates varied for the different treatments suggesting density dependence. On June 27, a sub-sample of 29 razorback suckers was taken from the low-density, and 157 from the high-density group. The mean total length for the high-density group was 27.7 mm, for the low-density group it was 33.2 mm.

On July 23-30, razorback suckers collected outside the enclosures averaged 90 mm. During depletion sampling (July 30-August 13) razorback sucker in the low-density enclosure averaged 69 mm, in the high-density enclosure they averaged 58 mm, and in the control enclosure they averaged 69 mm.

At the end of the study (October 8, 2002), razorback suckers that had been released into the main wetland had grown to an average length of 163 mm, with a range of 95-294 mm. The average growth per day was 1.1mm for the 139 days of the study.

Bonytail

Survival

Abundance of bonytail at the termination of the study was estimated to be 952 (95% CI = 941-972) in the high-density enclosure, and 368 (95% CI = 364-381) in the low-density enclosure. A total of 898 were harvested from the control enclosure. This equates to 1.3% survival in the high-density enclosure, 1.7% in the low-density enclosure and 17.1% in the control enclosure. The population outside the enclosures was estimated the last week of July to be 11,553 bonytail (95% CI = 9,649-13,915), twelve percent of the bonytail introduced had escaped the enclosure. Therefore, survival estimates within enclosures are conservative, as it is likely that fish escaped as larvae through very small holes and would have difficulty reentering the enclosures after they grew.

Growth

Bonytail were sampled on June 22 with a single fyke net per enclosure to measure growth rates. Bonytail were the most numerous fish captured in each net on this date.

However, nonnative age-0 fish were observed to be abundant in the enclosures, but the mesh size of the fyke nets (0.32 mm) was too large to adequately capture smaller individuals. On this date, no significant difference in mean total length of bonytail was observed between high 47.2 mm (std 5.6 mm), and low-density 46.5 mm (4.9 std mm) enclosures. Samples were not taken from the control enclosure.

Fish were again sampled between July 30-August 13, 2003. Growth rates for fish in both enclosures were 0.8 mm/d for the 51 days following stocking. Total length of bonytail harvested from study enclosures was 63.0 mm (std 7.7 mm) in high-density enclosures, 57.4 mm (std 7.0 mm) in low-density enclosures, 51.3 mm (std 5.8 mm) in the control enclosure, and 95.0 mm (std 8.2 mm) from outside the enclosures.

Nonnative Fish

The nonnative fish introduced into the enclosures reproduced and the populations quickly grew to very large numbers (Table 6 through Table 8).

The estimate for the black bullhead, green sunfish and fathead minnow assemblage exceeds 40,000 for both enclosures (Table 9). The nonnative fish predators were well represented in the study. Population estimates for carp and red shiner were not calculated because very few individuals of these species were captured.

Table 6. Capture data for black bullheads, green sunfish and fathead minnows in the low-density enclosure at The Stirrup floodplain wetland, Green River (RM 276.0) during each sampling period, July and August 2002.

	Black bullheads		Green sunfish		Fathead minnows	
Date	Number captured	Cumulative total	Number captured	Cumulative total	Number captured	Cumulative total
July 31, 2002	2,731	0	7,702	0	4,024	0
August 2, 2002	873	2,731	5,209	7,702	2,878	4,024
August 7, 2002	541	3,604	3,604	12,911	2,285	6,902
August 9, 2002	280	4,145	1,805	16,515	2,752	9,187
Totals	4,425		18,320		11,939	

Table 7. Capture data for black bullheads, green sunfish and fathead minnows in the high-density enclosure at The Stirrup floodplain wetland, Green River (RM 276.0) during each sampling period in July and August 2002.

	Black bullheads		Green sunfish		Fathead minnows	
Date	Number captured	Cumulative total	Number captured	Cumulative total	Number captured	Cumulative total
July 30, 2002	2,821	0	4,785	0	2,797	0
August 1, 2002	83	2,821	5,093	4,785	652	2,797
August 6, 2002	40	2,904	3,744	9,878	2,313	3,449
August 8, 2002	4	2,944	2,392	13,622	1,742	5,762
August 13, 2002	277	2,948	1,760	16,014	732	7,504
Totals	3,225		17,774		8,236	

Table 8. Capture data for black bullheads, green sunfish and fathead minnows outside enclosures at The Stirrup floodplain wetland, Green River (RM 276.0) during each sampling period, July 2002.

		Black bullheads		Green sunfish		Fathead minnows	
Date	Net hours	Number captured	CPUE Fish/hr	Number captured	CPUE Fish/hr	Number captured	CPUE Fish/hr
July 23, 2002	190.5	82	0.4	1,326	7.0	4,007	21.0
July 24, 2002	106.7	149	1.4	551	5.2	1,366	12.8
July 25, 2002	102.7	955	9.3	1,591	15.5	707	6.9
July 30, 2002	116.0	491	4.2	985	8.5	346	3.0
Totals	515.9	1,677		4,453		6,426	

Outside the enclosures fathead minnow CPUE did decline during sampling, resulting in a population estimate of 6,319 fish with 95% confidence limits between 5,933 and 6,706 fish. Capture data for black bullhead, green sunfish and fathead minnow caught outside the enclosures in late July are summarized in Table 9. Population estimates for black bullhead and green sunfish could not be calculated using depletion techniques because catch-per-unit-effort (CPUE) did not decline during sampling.

Table 9. Summary of population depletion-removal estimates for black bullheads, green sunfish and fathead minnows in each 0.10 hectare enclosure at The Stirrup floodplain wetland, Green River (RM 276.0) July 30-August 13, 2002.

	Black bullheads			Green sunfish			Fathead minnows		
Area	Nhat	Lower	Upper	Nhat	Lower	Upper	Nhat	Lower	Upper
Low-density	4,465	4,116	4,814	22,456	20,547	24,366	24,031	6,949	41,114
High-density	3,014	2,855	3,173	25,954	17,917	33,991	11,907	0	23,832

DISCUSSION

It is important to note that this study was designed to evaluate larval razorback sucker and bonytail survival in a natural floodplain depression. Natural in this case includes nonnative fish predators and competitors.

The essence of the reset theory is the timing of larvae entering the floodplain. Age-0 nonnative species did not appear for almost two weeks following endangered larval fish introduction. It appears that endangered larval fish can withstand the predation from the relatively few adult non-native fish that enter the floodplain at connection. Past experience has suggested that they cannot withstand the predation present when they enter floodplains that contain large numbers and multiple cohorts of non-native fish that over-wintered (Birchell and Christopherson 2004).

Zooplankton peaks occurred shortly after the floodplain filled allowing for optimum food availability with minimal inter-species competition. Thus, when the greatest concentration of zooplankton was available, little inter-species competition existed and growth rates approximated 1 mm/d. With the fast growth start, larval endangered fish were able to maintain a size advantage over many nonnative fish young-of-year spawned in the site.

Size was also likely a major factor in avoiding predation. The larval endangered fish were able to grow fast enough to avoid predation by the numerous age-0 non-native predators. Conversely, in the study by Birchell and Christopherson (2004), multiple age classes of non-native predators, which included juvenile black bullhead and green sunfish, likely predated heavily on endangered larval fishes.

The timing of the larval introduction was similar to their natural appearance in floodplains. Razorback sucker spawn on the ascending limb of the hydrograph and are among the first fish in this system to spawn each spring. Larvae drift into floodplains as they are connecting with the river (Modde et al. 2001). Bonytail spawn and recruit in floodplain impoundments in the lower Colorado River, albeit in the absence of nonnative fishes (Mueller et al. 2003). However, if bonytail adults remain in floodplain depressions, temperatures exceed 20^{o}C in early June and spawning would likely take place before or at the same time as nonnative fishes.

Percent survival estimates for larval razorback sucker sympatric with nonnative fish were low. The results and behavioral observations during the study support the conclusion of Johnson et al. (1993) that larval razorback sucker are predator naïve and unlikely to survive with high numbers of nonnative fish. Razorback sucker larvae could frequently be observed swimming in large groups in open water in the same vicinity as large predators. They did not appear to use the available cover or avoid predators (Birchell and Christopherson 2004). This was also captured with underwater video.

Survival of over 3,000 razorback suckers is encouraging. This is the first time larval razorback sucker survival has been detected in the middle Green River since 1996 when Levee Removal and associated studies began (Birchell et al. 2002; and Birchell and Christopherson 2004). If one applies the 56-72 percent survival reported in the 1999 study for 90 mm razorback sucker (Birchell and Christopherson 2004), The Stirrup could have contributed 1,000 to 2,000 sub-adult razorback suckers to the river population. However, caution should be used projecting survival this way.

Small numbers of larval fish escaped from the enclosures, but it is impossible to determine from which enclosure fish escaped. Escapement of larval fish from enclosures reduced survival estimates. However, the population estimate for the razorback suckers outside of the enclosures was relatively low (1,113). Because there were fewer predators outside the enclosures it is assumed that survival for fish that escaped was better than for fish inside the enclosures. Had those fish remained inside the enclosures survival estimates would have only been slightly higher and the conclusions would have remained the same.

This study demonstrated that larval razorback sucker survival could occur following a reset of nonnative fish populations. However, this survival occurred in a controlled environment and the following factors should be considered.

1. Although the nonnative fish numbers introduced into the enclosures were based on actual data, they still represent an estimate of what actually may occur in different years.
2. Fish were contained in a relatively small area (0.10 hectares).

Enclosures were used for two reasons. First, enclosures increase sampling efficiency. Second, enclosures allow for testing larval razorback sucker survival at different densities in the same floodplain. The densities of larval razorback suckers used for this study are likely higher than densities that would result from natural reproduction in the river and entrainment in the floodplain. Prior to this study, it was not known if razorback suckers could survive in the face of intense predation at any larval razorback sucker density.

Survival rates of fish introduced were nearly identical in both high and low-density enclosures, and were predictably much lower than the control enclosure.

Based on the number of non-native fish observed in the first year of the Levee Removal study, this study demonstrated that the floodplain 'reset' approach could work allowing recruitment of naturally spawned endangered fish to significantly contribute to recovery. However, several questions remain before this concept can be effectively implemented into recovery actions. These questions include: what factors most affect survival, (i.e., density of larvae, density of predators, or physical characteristics of floodplains)? Most likely all of these factors have an effect.

Increasing the number of spawning adults, and/or the number of spawning sites may enhance densities of larvae. Predator density may be managed through the frequency of flood plain reset, which is a function of flows and levee breach configuration (Birchell et al. 2002).

This study suggests that larval entrainment into floodplain depressions is one of the most important variables in improving wild razorback sucker survival.   Methods to improve larval razorback sucker entrainment should be evaluated and implemented; these include, connection configuration, floodplain location, and river flows.

In reset floodplains fish survival is only important to recovery if endangered fish recruit back to the river before the site dries up in a low water year. Therefore, it is essential that we understand and optimize the conditions necessary for these fish to return to the river. Factors to evaluate include, water depth at the floodplain/river connection, water temperature, connection timing and duration.

CONCLUSIONS

- Razorback sucker and bonytail larvae survived and grew well in a reset floodplain with a simulated predator load.
- Survival in the control enclosure, without nonnative fish, was much higher 9.8% for razorback sucker and 17.1% for bonytail.
- The minimum density needed to achieve a target survival level was not established.

RECOMMENDATIONS

- Continue to manage floodplains based on the reset theory. Even with abundant non-native fish predators these habitats are important to endangered fish and should be used for recovery.
- Continue efforts to better define the density relationship between larval endangered fish survival and non-native fish under natural conditions.
- During the next high flow year, introduce larval razorback suckers into floodplain sites that are void of nonnative fish to test this theory under more natural conditions.
- Evaluate methods to improve larval razorback sucker entrainment including connection configuration, location, and river flows. Entraining large numbers of larvae may be needed for recovery.
- Evaluate conditions necessary for razorback suckers and bonytail to recruit back to the river.

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