Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

Growth of Razorback Sucker (*Xyrauchen texanus*) at Bubbling Ponds Fish Hatchery

U.S. Department of the Interior
Bureau of Reclamation

November 2011

Lower Colorado River Multi-Species Conservation Program
Steering Committee Members

Federal Participant Group

Bureau of Reclamation
U.S. Fish and Wildlife Service
National Park Service
Bureau of Land Management
Bureau of Indian Affairs
Western Area Power Administration

Arizona Participant Group

Arizona Department of Water Resources
Arizona Electric Power Cooperative, Inc.
Arizona Game and Fish Department
Arizona Power Authority
Central Arizona Water Conservation District
Cibola Valley Irrigation and Drainage District
City of Bullhead City
City of Lake Havasu City
City of Mesa
City of Somerton
City of Yuma
Electrical District No. 3, Pinal County, Arizona
Golden Shores Water Conservation District
Mohave County Water Authority
Mohave Valley Irrigation and Drainage District
Mohave Water Conservation District
North Gila Valley Irrigation and Drainage District
Town of Fredonia
Town of Thatcher
Town of Wickenburg
Salt River Project Agricultural Improvement and Power District
Unit "B" Irrigation and Drainage District
Wellton-Mohawk Irrigation and Drainage District
Yuma County Water Users' Association
Yuma Irrigation District
Yuma Mesa Irrigation and Drainage District

Other Interested Parties Participant Group

QuadState County Government Coalition
Desert Wildlife Unlimited

California Participant Group

California Department of Fish and Game
City of Needles
Coachella Valley Water District
Colorado River Board of California
Bard Water District
Imperial Irrigation District
Los Angeles Department of Water and Power
Palo Verde Irrigation District
San Diego County Water Authority
Southern California Edison Company
Southern California Public Power Authority
The Metropolitan Water District of Southern California

Nevada Participant Group

Colorado River Commission of Nevada
Nevada Department of Wildlife
Southern Nevada Water Authority
Colorado River Commission Power Users
Basic Water Company

Native American Participant Group

Hualapai Tribe
Colorado River Indian Tribes
Chemehuevi Indian Tribe

Conservation Participant Group

Ducks Unlimited
Lower Colorado River RC&D Area, Inc.
The Nature Conservancy

Lower Colorado River Multi-Species Conservation Program

Growth of Razorback Sucker (*Xyrauchen texanus*) at Bubbling Ponds Fish Hatchery

Prepared by:

Matthew W. O'Neill, David L. Ward, and William T. Stewart, Arizona Game and Fish Department, Research Branch[1]

[1] 5000 West Carefree Highway, Phoenix, AZ 85086

Lower Colorado River
Multi-Species Conservation Program
Bureau of Reclamation
Lower Colorado Region
Boulder City, Nevada
http://www.lcrmscp.gov

November 2011

Table of Contents

List of Tables and Figures

Executive Summary

The few remaining razorback sucker populations are sustained by captive rearing and stocking programs, and the survival of stocked suckers in the wild is largely associated with size at stocking. Experimental studies at Bubbling Ponds Fish Hatchery, AZ have been ongoing for the last 5 years to understand factors that affect razorback sucker growth in captivity and to identify ways to improve growth rates and maximize size at release. This work consists of a literature review, an experimental study of disease treatment effects, and observations of individual fish growth in ponds under different conditions.

Literature review

A literature review and hatchery site visits concluded that razorback sucker growth is extremely variable and impacted by many factors including fish size and age, sex, density, amount of living space, quality and quantity of food, genetics and temperature. Culture practices for razorback suckers vary widely and include differences in rearing environments, rearing densities, feeding regimes and types of feed as well as grading or sorting practices. Calculated growth rates from the literature vary widely and range from 0.2 – 1.8 mm/day, with the highest growth rates reported from natural or semi-natural pond environments. These growth rates indicate that juvenile razorback suckers have a very hig growth potential under ideal rearing conditions.

Growth during disease treatments

Formalin, copper sulfate, potassium permanganate and salt are all chemicals commonly used to treat *Ichthyophthirius multifiliis* and other disease outbreaks in hatchery populations of razorback sucker. We exposed juvenile razorback suckers to 5, 5-day treatments with each chemical to evaluate the effects these chemicals may have on growth. Fish grew an average of 23.5 mm TL during the 3 month study period. No significant differences in growth were observed among fish treated with any of the chemicals compared to untreated fish ($p>0.05$). Reductions in growth as a result of repeated chemical treatments are not likely the cause of differences in growth rates among facilities that raise razorback suckers. Repeated chemical treatments may have other impacts to overall fitness or long-term survival, but these effects were not evident in our study.

Pond growth studies

Growth studies were conducted at the Bubbling Ponds Fish Hatchery from 2009 to 2011. These studies were largely observational because hatchery production requirements prevented experimental manipulation of dependent variables. Our initial work identified razorback growth rates in lined ponds at standard fish density as 0.26 to 0.28mm/day (7.89 to 8.43 mm/month). Additional studies include observations of growth rates in lined and unlined ponds, fish at different densities, sorting practices, and growth in the absence of the ectoparasite Ich.

Our data suggests that growth rates at the Bubbling Ponds Fish Hatchery are likely as high as possible given the pond densities required to meet production goals and the Ich-infested water that feeds the facility. Sorting practices are successful in helping as many fish as possible reach stocking length as fast as possible. Unlined ponds may be able to grow large fish at low densities, but whatever factors allow for that growth are not able to overcome high fish density. Growth rates were highest following removal of Ich from the Bubbling Ponds Spring 0.32 mm/day (9.6 mm/month), but that growth rate decreased again as Ich re-infested the hatchery.

Conclusions

We conclude that under typical hatchery operations (maximizing number of fish produced) the growth rate of razorback suckers is relatively consistent at Bubbling Ponds hatchery at 0.2-0.3 mm/day (6-9 mm/month), but is lower than growth rates at other facilities (0.2 – 1.8 mm/day, Ward et al. 2007). This growth rate has been constant in both lined and unlined ponds at all fish densities we were able to measure, is temperature independent, and is likely enhanced by separating fast and slow-growing fish after the first year of growth. To achieve growth rates substantially higher than this will likely require significant changes in rearing practices that may not be practical in order to reach numerical production goals.

Two major changes that might result in higher growth rates are substantially reducing fish density and modifying the way spring water is delivered to the facility (via either repeated chemical treatments or enclosed, concrete water diversions) to eliminate Ich from the hatchery source water. Other potential changes not address by our work include flow-training razorbacks; much previous literature, including MSCP-funded work on razorback suckers, suggests that fish growing in flowing water will grow faster than fish in still water (Jorgensen and Jobling, 1994). Furthermore, there are a wide variety of potential benefits associated with growing fish in flowing water in addition to increased growth rates (Davidson, 1997; Castro et al. 2011). Finally, given that stocking of smaller razorbacks has been largely unsuccessful, perhaps BPH goals could be changed from producing 12,000 fish at 300+ mm per year to a smaller number of very large fish each year. Growing fewer, larger fish could potentially be accomplished in the same time frame as more, smaller fish, but a better understanding of how density alters growth rate would be required to be confident of this.

I. Literature Review

Section Summary

The few remaining razorback sucker populations are sustained by captive rearing and stocking programs. Captive-reared razorback suckers commonly experience high predation when stocked into natural environments. This creates the need to rear fish to larger sizes in captivity and to find new ways to improve growth for captive-reared fish. We reviewed published literature and agency reports for information on factors that affect growth of razorback sucker. Site visits to razorback sucker production facilities and surveys of fish hatchery personnel were conducted to obtain information on current rearing practices. Razorback sucker growth is extremely variable and impacted by many factors including fish size and age, sex, density, amount of living space, quality and quantity of food, genetics and temperature. This makes evaluations of individual factors that affect growth difficult. Culture practices for razorback suckers vary widely and include differences in rearing environments, rearing densities, feeding regimes and types of feed as well as grading or sorting practices. The focus at most razorback rearing facilities is production, so the types of data that are collected are often insufficient for detailed evaluations of rearing practices on growth. Calculated growth rates from the literature vary widely and range from 0.2 – 1.8 mm/day. Typically the highest growth rates are reported from natural or semi-natural pond environments. These growth rates indicate that juvenile razorback suckers have a very high growth potential under ideal rearing conditions. Detailed, replicated studies are needed to accurately compare the effects of individual rearing practices on growth. These types of studies will ultimately provide both time and cost-savings to production facilities by reducing the time it takes for razorback suckers to reach stocking size, improving overall production efficiency.

Introduction

State and federal wildlife management agencies have been rearing razorback suckers in captivity since the 1970's (Toney 1974, Hamman 1985) to augment declining natural populations. Both wild-caught larvae and captive-bred fish are reared at fish hatcheries and grow-out ponds throughout the southwestern United States (reviewed in Mueller 2006). Each facility has unique environmental conditions and different rearing methods which yield different growth rates. Unlike commercial fish species, which have been cultured and studied extensively, little published information is available on the effects of various rearing methods on growth of razorback sucker.

Low survival rates of stocked razorback suckers (Brooks 1986, Marsh and Brooks 1989, Marsh and Pacey 2005) have caused target sizes for stocking to steadily increase in efforts to reduce predation mortality (Marsh et al. 2005, Schooley and Marsh 2007). Rearing fish to larger sizes comes with increased costs and creates the need to know which factors have the greatest impact on growth rate, and how these factors can be controlled to maximize growth. This document compiles and summarizes information on current captive rearing practices and associated growth rates for razorback sucker.

We reviewed relevant published literature and agency reports on razorback sucker to compile background information regarding the effects of environmental factors and rearing methods on growth. A questionnaire was developed (Appendix 1) and sent to hatchery managers who rear razorback suckers. Follow up surveys were also conducted by telephone (Appendix 2). Information on rearing densities, water quality, diseases, and management practices at each facility were recorded. Site visits to Bubbling Ponds State Fish Hatchery in Arizona, Dexter National Fish Hatchery in New Mexico, Grand Valley Endangered Fish Facility in Colorado, Ouray National Fish Hatchery in Utah, and the Willow Beach National Fish Hatchery in Arizona were also conducted as part of this knowledge assessment. Telephone interviews were conducted with personnel from other locations that produce razorback suckers (Uvalde National Fish Hatchery, Hualapai Ponds, Lake Mead Fish Hatchery, and J.W. Mumma Fish Hatchery) or facilities that formerly produced razorback suckers but currently focus on other species (Wahweap Fish Hatchery, Achii Hanyo National Fish Hatchery, Mora National Fish Hatchery).

Information from all of these sources is summarized to aid future researchers in the design of more detailed studies on razorback sucker growth. Understanding the factors that control razorback sucker growth will allow expanded fish-rearing capabilities and aid in reaching management objectives for stocked fish. Preservation of genetic resources for razorback suckers depends on captive rearing and stocking programs until permanent solutions to factors that prevent wild recruitment can be found.

Summary of Facilities

There are over 50 locations that have been used to rear razorback suckers (Table 1). These include both intensive culture facilities with raceways or circular tanks, as well as production ponds, golf-course ponds and natural floodplain-wetlands. The majority of razorback suckers that are stocked come from six major production facilities: Bubbling Ponds State Fish Hatchery, The Grand Valley Endangered Fish Facility, and Dexter, Ouray, Willow Beach, and Uvalde National Fish Hatcheries. Tables 2-3 outline the types of fish holding facilities and water quality conditions that exist at each of these main production locations. A brief summary of procedures for rearing razorback suckers at each of these facilities follows.*

* These summaries are based on interviews conducted with hatchery personnel in July 2007 during site visits. This information is provided only to give a brief overview of razorback grow-out procedures. Please verify accuracy of specific information with individual hatchery managers.

Table 1. List of locations that have been used to grow-out razorback suckers.

Facility	Location	Citation
Fish Hatcheries		
Bubbling Ponds State Fish Hatchery	Page Springs, Arizona	Mueller 2006
Grand Junction Endangered Fish Facility	Grand Junction, Colorado	Czapla 2002, Pfeifer 2000, Nesler et al 2003, Bingham et al 2003
(24-road Hatchery)		
Dexter National Fish Hatchery	Dexter, New Mexico	Uliberri 2003a
Mumma State Fish Hatchery	Near Alamosa, Colorado	Schnoor and logan 2002
Lake Mead Hatchery	Boulder City, Nevada	USBR 2006
Ouray National Fish Hatchery	Near Vernal, Utah	Czapla 2002, Irving et al 2004, Pfeifer et al 2003, Mueller 2006, USFWS 1999
Uvalde National Fish Hatchery	Uvalde, Texas	USBR 2006
Wahweap Fish Hatchery	Bigwater, Utah	Czapla 2002, Gustavson and Bradwisch 2000
Willow Beach National Fish Hatchery	Below Hoover Dam on Colorado River, Arizona	Hanson 1996
Achii Hanyo	Near Parker, Arizona	USFWS 2005
Colorado Grow-out ponds		
Peters ponds	Grand Junction, Colorado	Thad Bingham, personal communication
26 road pond	Grand Junction, Colorado	Pfeifer et al. 1999
Bounds pond 7	Grand Junction, Colorado	Pfeifer et al. 1999
Clymers Pond	Confluence of Colorado and Gunnison	Pfeifer et al. 1999, Czapla 2002
Colorado - 18 additional leased ponds	Grand Valley, Colorado	Pfeifer 2000
Dike road pond	Grand Valley, Colorado	Pfeifer et al. 1999
Highline ponds	Grand Valley, Colorado	Pfeifer et al. 1999
Horsethief rearing ponds	Grand Junction, Colorado	Pfeifer 2000, Czapla 2002
Golf Courses		
Blythe municipal golf course	Blythe, California	
Karsten golf course/ ASU Research Park	Mesa, Arizona	Marsh 1994, Marsh 1987
Page golf course ponds	Page, Arizona	Mueller and Wick 1998
Wildlife Refuges		
Buenos aires NWR	South of Tucson, Arizona	Marsh 1987
Cibola High Levee Pond	Cibola National Wildlife Refuge, Near Blythe, California	Marsh 2000, Minckley and LaBarbara 1999, Mueller 2006
Overton wildlife Management area	Near Lake Mead inflow, Nevada	USBR 2006
Senator Wash	North of Yuma, Arizona	Kretschmann and Leslie 2006, Minckley and LaBarbara 1999
Backwaters		
Davis cove	Lake Mohave, Arizona	Mueller 1992, Mueller and Burke 2005
Arizona juvenile	Lake Mohave, Arizona	Salisbury 1998
South Sidewinder	Lake Mohave, Arizona	Salisbury 1998
Yuma Cove	Lake Mohave, Arizona	Mueller 1992, Mueller and Burke 2005
Dandy	Lake Mohave, Nevada	Salisbury 1998
North Chemeheuvie	Lake Mohave, Nevada	Salisbury 1998
North 9 Mile	Lake Mohave, Nevada	Ty Wolters USBR, personal communication
Willow	Lake Mohave, Nevada	Ty Wolters USBR, personal communication
Nevada Egg	Lake Mohave, Nevada	Ty Wolters USBR, personal communication
Nevada Larvae	Lake Mohave, Nevada	Ty Wolters USBR, personal communication
Green River Floodplain Wetlands		
Above Brennan	Near Vernal, Utah	Pfeifer et al. 2003
Bonanza Bridge	Near Vernal, Utah	Pfeifer et al. 2003
Johnson bottom	Near Vernal, Utah	Modde and Haines 2005
Leota 10	Near Vernal, Utah	USFWS 1999
Leota bottom	Near Vernal, Utah	Modde and Haines 2005
Old charley Wash	Near Vernal, Utah	Modde and Haines 2005, Modde 1996
Leased ponds in the Uintah basin	Near Vernal, Utah	Irving et al 2004, Pfeifer et al 2003
Other		
Floyd Lamb state park (Tuele spring)	Las Vegas, Nevada	Marsh 1994
Trinidad State Junior College	Alamosa, Colorado	Schnoor and Logan 2002
Grow-out ponds	Near Farmingotn, NM	Schnoor and Logan 2002

Table 2. Facilities available at major razorback sucker fish hatcheries.

Location	Water Source	Type of Facility	Number	Size (Surface Acres)	Volume (Gallons)	Flow (gpm)
Bubbling Ponds Fish Hatchery	Open spring , 2200 gpm	Lined Pond	6	0.25	1,000,000	275
		Earthen pond	2	0.25	1,000,000	275
		Linear Raceways	3		2,250	
		Square concrete tank	2		6,300	
		Circular tank	6		650	
Dexter National Fish Hatchery	5 shallow aquifer wells, 2000 gpm	Lined/Earthen ponds	46	0.1 to 1.0		
		Linear Raceways	4		5,500	
		Rectangular tanks	20		540	
		Circular tanks	40		120	
		Circular tanks	50		200	
		Aquaria	80		10	
		Aquaria	20		40	
Grand Junction Native Fish Facility	Municipal drinking water	Circular tank	14		900	12
Horsethief rearing ponds	Pumped river water	Circular tank	78		200	5
		Earthen Pond	8	0.25 – 0.5		
Ouray National Fish Hatchery	7 shallow wells, 600 gpm	Lined pond	24	0.125 - 0.25		10
		Circular tank	30		120	5
		Circular tank	27		900	10 to 15
Willow Beach National Fish Hatchery	Solar heated Colorado River water	Linear Raceway	3		1,500	
		Linear Raceway	16		16,000	
		Aquaria	60		10	
Uvalde National Fish Hatchery	2 Deep Aquifer Wells, 1500 gpm	Lined ponds	11	1		
		Earthen ponds	37	.25 – 1.0		
		Linear Raceways	2		6,500	
		Linear Raceways	12		1,000	
		Circular tanks	12		200	
		Circular tanks	3		3,000	

Table 3. Water quality ranges at each culture facility.

Location	Parameters	Season Spring (Mar-May)	Summer (Jun-Aug)	Fall (Sept-Nov)	Winter (Dec-Feb)
Bubbling Ponds	Temperature (C)	15-20	22-24	19-21	13-16
	pH	7.8-8.0	7.3-8.6	7.3-8.4	7.3-8.0
	D.O. (mg/L)	5.8-14.0	5.8-14.0	5.8-14.0	5.8-14.0
	Alkalinity (mg/L)				
	Pathogens	Ich, Costia Trichodina Aeromonas/Psuedomonas Columnaris	Ich, Costia Trichodina Aeromonas Columnaris	Ich, Costia Trichodina Aeromonas Columnaris	Ich, Costia Trichodina Aeromonas Columnaris
Dexter	Temperature (C)	17-20	22-28	17-20	10-16
	pH	7.5-8.5	7.5	8.5	7.5
	D.O. (mg/L)	2.8-9.7	2.8-9.7	2.8-9.7	2.8-9.7
	Alkalinity (mg/L)	165-188	165-188	165-188	165-188
	Pathogens	Minimal - only what is brought in with incoming fish			
Grand Junction	Temperature (C)	23-25	23-25	23-25	23-25
	pH	7.7-8.0	7.7-8.0	7.7-8.0	7.7-8.0
	D.O. (mg/L)	7.0-7.5	6.5-7.0	6.0-6.5	4.5-6.5
	Alkalinity (mg/L)	100	100	100	100
	Pathogens	None at intensive culture facility, Ich at broodstock ponds			
Ouray	Temperature (C)	11-25	11-25	11-25	11-25
	pH	7.4-8.2	7.4-8.2	7.4-8.2	7.4-8.2
	D.O. (mg/L)	5.0-12	5.0-7.2	5.0-7.2	5.0-7.2
	Alkalinity (mg/L)	119	119	119	119
	Pathogens	Costia	Costia	Costia	Costia
Willow Beach	Temperature (C)	17-20	20-25	17-20	13-18
	pH	7.5-8.0	7.5-8.0	7.5-8.0	7.5-8.0
	D.O. (mg/L)	3.0-9.0	3.0-6.0	3.0-9.0	4.0-9.0
	Alkalinity (mg/L)	300-400	300-400	300-400	300-400
	Pathogens	Ich, Costia Columnaris Aeromonas	Ich, Costia Columnaris Aeromonas	Ich, Costia Columnaris Aeromonas	Ich, Costia Columnaris Aeromonas
Uvalde	Temperature (C)	19-26	26-28	18-28	14-18
	pH	7.7-8.2	7.7-8.2	7.7-8.2	7.7-8.2
	D.O. (mg/L)	4.0-12.0	4.0-12.0	4.0-12.0	4.0-12.0
	Alkalinity (mg/L)	226	226	226	226
	Pathogens		Columnaris		

Bubbling Ponds State fish Hatchery

Bubbling Ponds Fish Hatchery in Arizona does not maintain razorback sucker broodstock on site. Razorback suckers are received either as juveniles from Willow Beach National Fish Hatchery or as newly-hatched larvae from Dexter National Fish Hatchery. Larval fish are typically placed into an unfertilized, unlined, 0.6 acre pond in the spring. In September, the pond is harvested by draining the pond and seining. All fish that have reached the target size (300 mm TL) are stocked. Fish that are too small to stock are split up equally between the six remaining grow-out pond at an average density of about 5,000 – 7,000 fish per pond. Fish are fed by hand at approximately 2.5% body weight, split between morning and evening feedings. Fish are either fed a catfish diet made by Rangen®

that is enriched with spirulina and krill, or razorback sucker diet, made by Silvercup® depending on availability. Fish are monitored visually and by sampling using a cast net. When a large number of fish have grown to the target size they are harvested by draining the pond and seining. Fish are again sorted by hand and the largest fish are stocked. Fish that have not reached the target size are returned to the ponds for further grow-out. On average it takes one to two years for fish to reach the target size with fish growing an average of 0.6 mm/day. Target numbers for production are 12,000 razorback suckers annually (300 mm TL). The biggest difficulty in rearing razorback suckers at Bubbling Ponds Fish Hatchery is protozoan parasite infestations (Ich) and associated bacterial infections that come from an open spring source that is inhabited by mosquitofish.

Dexter National Fish Hatchery

Dexter National Fish Hatchery maintains four separate razorback sucker broodstocks. These fish are spawned on site and larval fish are placed directly into 0.1 acre ponds at a density of about 20,000 larvae per pond (50 – 100 thousand per acre). Ponds are fertilized with alfalfa pellets and superphosphate two weeks prior to receiving larvae to produce natural feed for larval fish. Ponds are fertilized again with alfalfa pellets one week after larvae are introduced. Fish are fed a catfish starter diet (sizes 1-3) made by Rangen®, that is enhanced with spirulina and krill and then switched over to the razorback diet once they are large enough to eat 1mm crumble. Fish are fed twice a day by hand, four days a week at 2.5-6.0 % body weight. Feed ration is decreased if excess feed is seen remaining on the pond bottom following feedings. Fish are not graded or sorted during this grow-out period. Razorback suckers are harvested in the fall by draining ponds completely. Fish are sorted at harvest and distributed to other facilities for further grow-out depending on current size requirements. Razorback suckers are on average 100 – 200 mm TL after the first growing season and generally take 1 -18 months for a majority of the fish to reach 300 mm TL. There are 16 different species of fish maintained at Dexter National Fish Hatchery and having sufficient pond space to grow out separate groups of fish is the limiting factor for production of razorback suckers at this location.

Grand Valley Native Fish Facility

The Grand Valley Native Fish Facility maintains its own brood stock in eight ponds located at the Horsethief Basin Wildlife Area in Grand Junction, Colorado. Fish are spawned on site and larvae are reared indoors in fiberglass tanks at the 24-Road Fish Hatchery in Grand Junction. The 24-Road Hatchery consists of two separate recirculating systems that operate using de-chlorinated city water and two large fluidized- bed sand filters and rotating-drum filters for waste removal. Fish are held in 4-foot (n=78) or 8-foot (n=14) diameter fiberglass tanks. Larval fish are started on prepared feeds immediately after swim-up and fed exclusively razorback feeds made by Silvercup®. Fish are started on a 0-250 micron razorback diet for the first 10-12 days and then fed with gradually increasing feed sizes based on observations of feeding (250 – 400 micron, #1 starter). Feed sizes are mixed when transitioning to the next larger feed size. These razorback diets are specially sifted by Dr. Rick Barrows (USDA Hagerman experiment station, Idaho). Razorbacks are typically eating 1mm extruded pellets by the time they are 3.5 to 4 inches in length. Fish are fed approximately 7.0% body weight per day initially and then gradually reduced to 1.5 % body weight by the time they reach the 300 mm TL target size. Fish are fed seven days a week using 12-hr belt feeders. It takes 12-16 months to grow fish to the target size in the hatchery.

Razorback suckers are sorted after three months and culled to about 4,000 fish per family lot. Culled fish are stocked into leased grow-out ponds. Stocking densities for juveniles in these ponds is based on previous stocking and harvest rates and is pond specific. Grow-out ponds are harvested periodically using Fyke nets or trap nets and fish of the target size are stocked. Disease problems (Ich, Lernea), water quality problems (low DO), and difficulty in removing all of the fish are challenges for grow-out of razorback suckers in these natural ponds.

Fish reared in the 24-Road facility are sorted again at four to five months of age into small and large size groups to obtain more uniform growth rates. Batch estimates of fish weight are done every month for each tank. A group of fish are weighed and counted to give an average weight for the tank with lengths estimated based on a length/weight chart. The biggest difficulties for growing out razorback suckers at the 24-Road Fish Hatchery are insufficient space and water flow (oxygen) to grow fish to the target size. At the Horsethief

Basin Ponds where broodstock are reared, diseases such as Ich are problematic because water is pumped directly from the Colorado River.

Ouray National Fish Hatchery

Ouray National Fish Hatchery maintains its own broodstock and spawns fish on-site. Larvae are transferred from indoor hatching tanks to unfertilized 0.2 acre outdoor ponds and stocked at densities 10,000 – 20,000 larvae per pond. Even though outdoor ponds are covered with bird netting, avian predators still get caught in the nets if they can see fish. Ponds are dyed blue as the fish grow to prevent avian predation. While in the outdoor ponds, fish are fed a slow-sinking salmon diet made by Silvercup®, twice daily, by hand. Amount of feed is based on periodic sample counts. Fish are grown until late September at which time temperatures require that all fish, other than adult broodstock, be brought inside for the winter. Ponds are drained completely and fish are sorted by hand. Fish that have reached the target size (300 mm TL) are stocked into the Green and Colorado Rivers. All remaining fish are moved indoors and held in three-foot (n= 30) or eight-foot (n=27) diameter circular tanks. On average it takes 12 – 18 months to grow fish to the 300 mm TL at Ouray hatchery.

Razorback suckers are held during the winter in a recirculating system that operates using two large fluidized-bed sand filters and a rotating-drum filter for solids removal. Fish are fed the Silvercup® razorback diet using belt feeders. There is currently capacity to hold only 20,000, 200-300 mm TL fish inside the facility and any extra fish are stocked into floodplain-wetlands or used for research purposes. Ouray no longer leases any private grow-out ponds. Grow-out ponds were troublesome due to poor water quality, harvesting difficulties, and non-native fish introductions. The biggest difficulty for production of razorback suckers at the Ouray National Fish Hatchery is space during the winter to maintain large numbers of fish and high iron and manganese in the well water that must be filtered out prior to use.

Willow Beach National Fish Hatchery

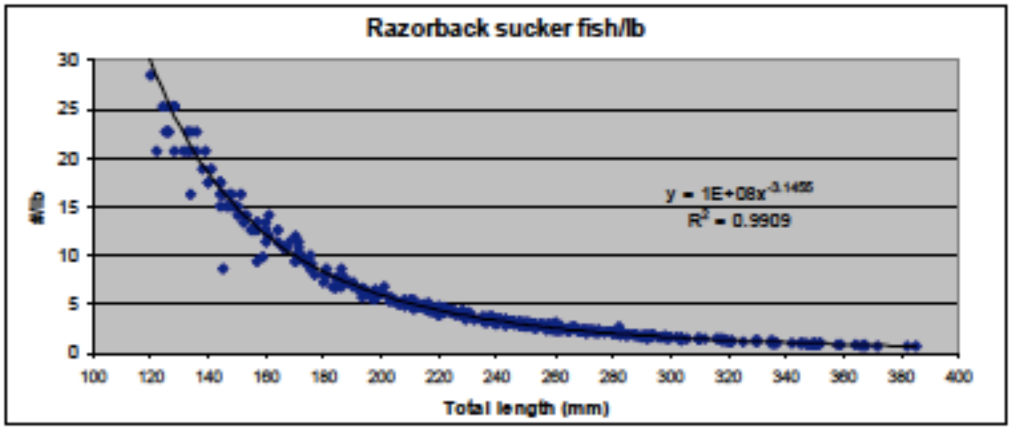
Willow Beach National Fish Hatchery receives wild-caught larvae from Lake Mohave. Larvae are treated for diseases with formalin and malachite green and placed in 45, ten-gallon flow-through aquaria. Recirculated, solar heated water, 22-25° C is used to allow production of warm water fish at this traditionally cold water facility. (Figiel 2003, Figiel et al. 2005). Fish are fed brine shrimp nauplii to satiation every hour and after 14 days small amounts of specialized larval fish diet (Encapsulon, Cyclopeeze, spirulina, and artificial plankton) are introduced. After 30-60 days fish are transferred to six, 32-gallon fiberglass troughs at densities of 1,000 to 1,500 fish per tank and then a month later moved outside to eight recirculating raceways that use a combination of well water and solar-heated water to maintain temperatures of 22 – 25° C during the summer months.

When in the outside raceways, fish are fed the razorback diet using belt feeders and fed by hand at 1.0 - 7.0% body weight per day. Feed amount is adjusted based on sample counts according to a feed conversion program developed for razorback suckers by Willow Beach Hatchery personnel. This program uses length and number-per-pound generated from several years of razorback growth data (Figure 1). Fish are sorted opportunistically and are not handled during the summer months when water temperatures are above 20°C. In 2004, the target size for stocking was 325 mm TL or greater (WBNFH 2004) with a target of producing 6,000 fish per year. Reaching this target size usually takes two growing seasons. The biggest difficulty in rearing razorback suckers at Willow Beach National Fish Hatchery is insufficient space to grow fish to increased target sizes (400-500 mm TL).

Uvalde National Fish Hatchery

Uvalde National Fish Hatchery in Texas receives 35,000 – 60,000 razorback sucker fry annually in March/April from Dexter National Fish Hatchery. The fry are acclimated in bags submerged in the pond for a minimum of one hour and released into a 1 acre fertilized pond, where they are reared for the remainder of the summer. Fingerlings are fed a starter razorback diet when they reach approximately 50 mm TL. In April/May, the previous year class of razorbacks are captured from their over-wintering pond, enumerated, graded, and split into one-acre grow-out ponds. Approximately 4,000 – 5,000 fish will be placed in each one acre pond for summer grow-out. Fish are reared for approximately 150 days (May –

Oct) and fed the Bozeman razorback diet two times a day/ five days a week at 1.5 – 3.0 % body weight per day, based on average water temperature.



* Developed by personnel at Willow Beach National Fish Hatchery using several years of growth data.

Figure 1. Relationship between length and number of fish per pound.

In general, juvenile razorback suckers (received as fry during the previous spring) reach the target size of 300 mm TL in approximately 6 months. In 2006/2007, Uvalde produced 6,000 razorback suckers, 300 mm TL for introduction into the San Juan River. Starting in 2008, Uvalde NFH will be producing and distributing 12,000- 300 mm TL razorbacks for stocking into the San Juan River. Predation from migrating cormorants has occurred, but timing of harvest and over wintering protection methods such as covering ponds with netting or placing fish indoors helps to minimize losses during the cormorant migration (November to March). Uvalde has experienced razorback mortalities because of bacterial problems but these are usually resolved through the use of oxytetracyline medicated feed.

Overview of Differences in Culture Methods

Several differences were noted when conducting surveys at each of the five main production facilities for razorback sucker (See Appendix 3). These differences include different stocking and rearing densities (Table 4-5), various feeding regimes and type of feeds (Table 7) as well as differences in grading or sorting practices. Some of these differences are related to whether or not razorback suckers are being reared in extensive-culture facilities (ponds) or intensive-culture settings (raceways o tanks). Some practices are unique to a single facility or a couple of facilities (Table 6). Managers at each facility were asked to identify the biggest difficulty or constraint that they experience when growing-out juvenile razorback suckers at their respective location. Space constraints, water quality and disease problems were the main factors limiting production of razorback suckers at these facilities (Table 8). Calculated or reported growth rates from the literature vary widely (Table 9) and range from 0.2 to 1.8 mm/day. These growth rates indicate that juvenile razorback suckers have a very high growth potential under optimal rearing conditions.

Table 4. Stocking densities for larvae and fry in ponds.

Location	Pond Size	Number of Fish	Fish Size	Number/Acre
Dexter	0.1	20,000	Larvae	50,000 - 100,000
Ouray	0.2	10,000 - 20,000	Larvae	50,000 - 100,000
Bubbling Por	0.25	5,000 - 7,000	Fry	20,000 - 28,000
Wahweap	0.4	5,000	Fry	12,500
Uvalde	1	35,000	Fry	35,000

Table 5. Rearing densities at intensive culture facilities.

Location	Size of tank	Gallons	Flow rate	Lbs of fish	Kg of fish	Max Lbs/gallon
Ouray	3 foot circular	120	5	20 - 53	9 - 24	0.44
	8 foot circular	850	10-15	42 - 146	19 - 66	0.17
Grand Junction	4 foot circular	200	5	16 - 66	7.5 - 30	0.33
	8 foot circular	850	12	66 - 253	30 - 115	0.29

Table 6. Rearing practices that are unique to specific rearing facilities.

Facility	Unique practice or methods
Bubbling Ponds	Larval fish reared in unfertilized unlined pond Higher water flows through ponds than at other facilities
Dexter	Fertilizes ponds prior to larvae introduction with alfalfa pellets and superphosphate
Grand Junction/Ouray	Use of fluidized-bed sand filters for removal of nitrates and nitrites
Horsethief Basin	Use of surface agitators for aeration in broodstock ponds
Lake Mead	Rearing of fish in square fiberglass tanks - 750 gallon
Ouray	Water dyes to prevent predation, supplemental aeration in ponds - air stones
Willow Beach	Artemia fed to larval fish, and specialized larval fish diets Rearing fish in recirculating outdoor raceways with solar heated water Attempted rearing fish in net pens in the Colorado River
Uvalde	Ponds are fertilized prior to receipt of fry to start them on a more natural diet

Table 7. Types of feed used at razorback sucker hatcheries.

Location	Holding environment	Larval fish	Juvenile to adult fish
Bubbling Ponds	Unlined pond	Unfertilized ponds, natural foods	Rangen¨ Catfish diet Silver Cup¨ razorback diet depending on availability
Dexter	Lined pond	Ponds fertilized with alfalpha pellets and superphosphate, natural foods	Rangen¨ Catfish diet Silver Cup¨ razorback diet once they are large enough to take 1 mm feed
Grand Junction	Fiberglass circular tank	0-250 micron razorback diet - 1st 10 days Progressively larger sifted razorback diet	Silver Cup¨ razorback diet Small sizes specially sifted by Rick Barrows
Ouray	Fiberglass circular tank Lined ponds	0-250 micron razorback diet - 1st 10 days Progressively larger sifted razorback diet	Silver Cup¨ razorback diet Silver Cup¨ Slow sinking salmon diet
Willow Beach Uvalde	Aquaria Fiberglass troughs Outdoor raceways Lined and unlined ponds	Brine shrimp naupli Encapsulon, Cyclopeeze, spirulina, and artificial plankton Ponds fertilized with alfalpha pellets and superphosphate; invertebrate production	Silver Cup¨ razorback diet Silver Cup¨ razorback diet Silver Cup¨ razorback diet

Table 8. Factors limiting production at major razorback sucker facilities.

Location	Biggest problem or factor limiting production
Bubbling Ponds	Disease problems associated with an open spring water source
Dexter	Space constraints - 16 different species on station makes it difficult to maintain separate razorback stocks
Grand Junction	Space constraints related to water quality and dissolved oxygen limitations of recirculating systems
Ouray	Water quality problems caused by high iron and manganese Winter temperatures that require all fish to be moved indoors Space constraints related to water quality and dissolved oxygen
Willow Beach	Space constraints. Growing fish to increasingly larger sizes results in insufficient space on station for new fish
Uvalde	Summer temps can get high-requiring power usage to triple due to higher groundwater pumping to keep ponds cool.

Table 9. Reported and calculated growth rates from the literature.

Location	Calculated Growth Rate (mm/day)	Citation	Comments
Arizona Juvenile, lake Mohave	0.95 *	Salisbury 1998	82 mm at stocking, 8 months of growth, density =1000 fish/acre
Bonita Creek	0.792*	Brooks 1986	40 mm juveniles, for 2 months
Cibola High Levee Pond	0.88 - 1.19 * .	Marsh 2000	57-167 mm fish out for 3 years
Cibola High Levee Pond	0.267	Minckley and LaBarbara 1999	3 years, fish caught with trammel nets
Cibola High Levee Pond	0.2 +	Mueller et al 2004	5 year study on tagged fish
Cibola High Levee Pond	0.2 +	Mueller 2006	86 fish, growth rate based on recaptures, growth slowed at 350 mm +
Dexter	0.426	Minckley 1983	ponds in 1981
Dexter	0.58 * .	Uliberri 2003b	200-250 mm stocked. Density = with 3,256/0.98 acre pond, 44.8 % achieved 305 mm
Floodplain wetland - Green river	0.48 - 0.77	Modde and Haines 2005	first 160 days of life
Floodplain wetland - Stirrup	0.6	Brunson and christopherson 2005	larval fish, 64 days
Floodplain wetland - Stirrup	0.4	Brunson and christopherson 2005	density of 18,000 larvae per acre
Floodplain wetland - Stirrup	0.92	Brunson and christopherson 2005	4,000 larvae per acre
Green River, floodplain wetland	0.71 - 1.08	Modde and Haines 2005	Larval fish, first few months of growth
Green River, floodplain wetlands	1.3	Birchell and christopherson 2004	100 mm, growth rates at Ouray were only 50 % that of floodplain wetlands
Humphrey pond, Colorado	1.4 *	Kaeding and osmundson 1989	55 mm at stocking, fertilized pond
Lake Mead	0.048 *	Ruppert 1999	Adult, Lake mead recaptures, out for 1 year
Lake Mohave backwater	1.11 * .	Burke 1995	Month old larvae stocked
Dandy backwater, Lake Mohave	0.97 *	Salisbury 1998	82 mm at stocking, 8 months of growth, density =1000 fish/acre
North Chemeheuvie, Mohave	0.78 *	Salisbury 1998	82 mm at stocking, 8 months of growth, density =1000 fish/acre
Ouray National Fish Hatchery	0.5 *	USFWS 1999	Average yearling in ponds
Ouray National Fish Hatchery	0.38 *	USFWS 1999	Average yearling in raceways or tanks
Ouray National Fish Hatchery	0.56 - 0.7 *	Tyus 1998	April to Oct in ponds, 127 mm to 157 mm at end of 1st season
Page, AZ golf course	0.54 - 0.68 * .	Mueller and Wick 1998	115 mm to 360 mm in 12 ▲| 15 month period, collected with trammel net
Rinderknecht pond, Utah	0.268 *	Pfeifer et al 2003	juvenile fish (145 mm) , stocked at 444 per acre
Uvalde	0.56 + *	USBR 2006	Stocked <200 mm, into 1/2 acre pond and harvested >300 mm six months later
Vincent Pond, Utah	0.382 *	Pfeifer et al 2003	Larval fish, stocked at 2500 per acre
Yuma Cove	1.06 *	Mueller 1995	Naturally spawned larval fish
Yuma Cove	1.8 * .	Mueller and Burke 2005	Stocked as 25 mm larvae, reached 300 mm by end of summer

* Calculated growth rates based on information provided in literature

[a] Approximations of maximum growth potential (based on average maximum sizes if fish reported at harvest

General Information on Factors that Affect Fish Growth

Growth in fish is extremely variable, and is impacted by many different physiological and environmental factors. Growth rates are known to change with size and age, sex, season, activity level, density, amount of living space, quality and quantity of food, genetics and temperature (Brett 1979). Growth experiments conducted at different times of year can result in growth rates that are not comparable. As fish become larger their physiological potential to grow decreases making determination of growth rate dependent on the size of the starting fish and the length of the experiment (Busacker et al. 1990). Genetic factors also have great potential to influence growth rate. Some species have strains and races that display vastly different growth potentials (Reinitz et al. 1979). All of these factors combine to make assessment of the individual factors controlling fish growth difficult.

Water temperature is probably the most important variable affecting growth rate. All of the basic functions that affect growth such as feeding, digestion, and metabolism, are temperature-dependent. Growth is inseparably tied to bioenergetics and therefore also tightly tied to temperature. When temperatures are below optimum, daily temperature fluctuations can stimulate growth. Photoperiod is also commonly linked to water temperature and can influence growth rates in fish (reviewed in Brett 1979).

Fish density is known to affect growth and can alter growth rates in several ways. Fish that exhibit strong territorial behaviors or natural schooling tendencies will experience reduced growth if densities are too high or too low (Brett 1979). Dominance hierarchies where some fish feed more aggressively than others can also lead to high variability in growth rates (Koebele 1985). Crowded conditions also cause physical interference between fish and poor water quality which reduces growth (Busacker et al. 1990). The effects of fish numbers, space and feeding opportunity are frequently correlated and often difficult to distinguish (Brett 1979).

It is impossible to study the effects of environmental factors on growth without also evaluating feed rations (Brett 1979). Amount of food, quality of the diet, particle size, number of feedings per day, and time of feeding have all been shown to affect growth (Busacker et al. 1990). In controlled laboratory studies food is usually fed ad libitum (constantly available) and other variables are altered to assess impacts of environmental factors on growth. These studies are usually conducted in tanks or raceways because researchers must verify that food is constantly available to the fish which is difficult to do in large pond environments where the fish and the bottom are often not visible (Busacker et al. 1990).

Specific Information o Razorback Sucker Growth

Variable growth

Growth in razorback suckers is naturally highly variable and may be a function of their evolutionary history (USFWS 2002). Minckley (1983) speculated that wide size variation in a single cohort of razorback suckers may be adaptive, with fast-growing fish that reproduce at a young age surviving better in high discharge years and slow-growing, smaller fish surviving better during drought periods. This highly variable growth rate makes rearing razorback suckers in a production setting difficult because fish from a single cohort do not reach the target stocking size simultaneously. One of the major tasks for aquaculture is to maximize both individual growth and total production (Gerking 1978). This becomes more difficult when the species being cultured exhibits highly variable growth rates because of genetic influences, as is the case with razorback suckers.

Razorback sucker growth is typically very rapid during the first year of life and then declines with age. First year growth can be as low as 50 mm and as high as 350 mm (Valdez et al. 1982, Minckley 1983, Mueller 1995). Razorback sucker grow rapidly for approximately the first five or six years of life and then growth slows (McCarthy and Minckely 1987, Tyus 1998, Minckley et al. 1991). Growth of older individuals in extant wild populations is very low (Minckley 1983, Tyus 1988, Modde et al. 1996). Wild growth rates for mature adult fish in Lake Mohave based on PIT tag recaptures were often too small to be accurately measured for both males and females over the time period of 1987-1997 (Marsh and Pacey 1998). This information suggest it will take substantially longer to rear fish to increasingly larger stocking sizes (400 – 500 mm TL) than it did to reach the target size of 300 mm TL.

Growth in ponds

One of the main strategies for maintaining genetic refugia and self-sustaining populations of razorback sucker in the lower Colorado River basin is to rear razorback sucker larvae in production ponds until they are a suitable size for stocking (USFWS 2004). Pond culture has proven useful to promote rapid growth of juvenile razorback suckers (Kaeding and Osmundson 1989). Marsh (1994) reported that growth rates of razorback suckers reared in golf-course ponds exceeded the best growth rates obtained under intensive culture conditions at federal hatcheries, especially during the first several years of life. Growth rates in these semi-natural ponds are also comparable to estimated growth rates of juvenile wild fish (McCarthy and Minckley 1987). Modde and Haines (2005) reported the greatest growth rates in the largest and deepest floodplains with the greatest amount of submergent vegetation, but excellent growth and survival of fish in a grow-out pond is of little value if there is not an efficient way to collect the fish from the pond (Kaeding and Osmundson 1989).

Temperature

Bulkley and Pimentel (1983) used shuttle boxes in the laboratory to determine a temperature preference for razorback suckers of 23-24°C. In their studies, razorback suckers were found to avoid temperatures below 11.8 °C or above 28.6 °C. Razorback suckers at Bubbling Ponds Hatchery are more active in the spring and feed better as photoperiod increases even prior to water temperatures rising (Frank Agygos, personal communication). Table 3 briefly summarizes water temperature data from each facility. Detailed, seasonal water temperature profiles are not currently available for many razorback grow-out sites.

Density

Extensive studies have been conducted on commercially important species to evaluate stocking densities and feeding rates that maximize production. For these species, controlled experiments under laboratory conditions have established relationships between temperature, density, and feed ration on growth (Brett 1979) but this information is sporadic or non-existent for razorback suckers (Bays et al. 2005). Fish culturists with experience rearing razorback suckers typically have target stocking densities that they use (Tables 4 - 5). These stocking densities have largely been determined over time by trial and error. These approximate stocking densities provide a good starting point for more controlled types of replicated pond studies.

Feed ration

Razorback suckers are currently being fed a wide variety of prepared diets (Table 7) that range from a slow-sinking salmon feed manufactured by Silver Cup® to a spirulina and krill-enhanced catfish feed made by Rangen®. Most locations are feeding 2.0 – 5.0 % body weight per day. Methods for culture of razorback sucker larvae in intensive settings at fish hatcheries are well documented (Figiel 2005) and various larval fish diets have been evaluated (Tyus and Severson 1990, Severson et al. 1992), but no standardized procedures are used for feeding larval fish in intensive settings.

Razorback sucker larvae are also effectively reared in pond environments using natural foods supplemented with larval fish diets and survival is high when no predators are present (Mueller 2006). Growth rates for larval and early juvenile razorback suckers may increase with pond fertilization. Diet and physiological studies on wild razorback suckers indicate that they feed on plankton as well as benthic organisms during their entire life (Marsh 1987). Artificially fertilizing ponds may greatly increase production capacity and growth rates for razorback sucker (Papoulias and Minckley 1992) and warrants further investigation.

Handling stress

Handling stress has been shown to influence growth rates. Paukert et al. (2005) found that growth of bonytail chub was reduced by 26% when compared with controls after being repeatedly captured and handled in hoop nets. Handling effects are likely to be similar for razorback suckers that are repeatedly captured and sorted in a hatchery setting. Razorback suckers that are handled at Willow Beach National Fish Hatchery will commonly not eat for two weeks after handling (John Scott personal communication). This creates a difficult situation for production facilities because fish need to be sorted to ensure large aggressive fish do not interfere with growth of smaller individuals, but frequent handling and sorting causes stress related reductions in growth.

Measuring Growth in Captive Fish

Weight is the traditional measure used to estimate growth or production in aquaculture settings. Groups of fish are typically weighed and an average individual weight is computed (Busacker et al. 1990). Although this method is often logistically the easiest, it may not be the most informative for species with highly variable growth rates like razorback suckers, especially when target lengths must be reached before fish can be stocked. Weight can also be highly influenced by things like stomach fullness or development of gonads (Busacker et al. 1990). Condition factor or relative weight can also be used to assess growth of fish, but these tools may be more robust predictors of fecundity than of growth (Anderson and Neuman 1996). For some species sexes need to be distinguished because males and females may differ in morphology (Anderson and Neumann 1996). Mueller (2006) analyzed growth rates based on PIT tag recaptures of 86 razorback suckers in High Levee Pond and found that differences in growth do not appear to occur until fish are over 450 mm TL at which time growth rate in males slows while females continue to grow at a slightly higher rate. This would indicate that sex may not be an important factor to consider when examining growth rates unless the target grow-out size is above 450 mm TL.

The best measures of growth are often determined from the length and weight of individuals rather than from groups of fish (Anderson and Nuemannn 1996) because individual growth rates give better estimates of confidence and variance (Busacker et al. 1990). Length frequency analysis or recapture of previously marked individuals of a known size is likely to yield the most useful information for razorback sucker growth. The success of any of these methods depends on proper sampling procedures that are representative of the population as a whole (Busacker et al. 1990). Sampling methods that are known to be size-biased such as trammel nets (Mueller et al. 2004) or cast nets should not be used when trying to measure growth rates.

Conclusions

For razorback sucker, survival is largely associated with stocking size. Additional focused research is therefore needed to identify ways to increase growth rates of captive-reared razorback sucker. Growth rate in fish is controlled by many factors including fish size and age, temperature, density, and feed ration, which can all be highly correlated. Growth of razorback suckers is also inherently variable which makes the task of identifying the key factors that affect growth in captivity even more difficult. The focus at most razorback rearing facilities is production, so the types of data that are collected are often insufficient for detailed evaluations of individual rearing practices on growth. Surveys of existing razorback sucker rearing facilities indicate that culture methods vary widely and the types of growth data that are collected are not standardized. Replicated studies with detailed information on rearing location, water temperature, initial stocking size, stocking density, and the sizes of all fish at harvest are needed in order to compare the effects of individual rearing practices on growth. This type of research will ultimately provide both time and cost-savings to production facilities by reducing the amount of time necessary for razorback sucker to reach stocking size, improving overall production efficiency.

Optimum rearing densities for razorback sucker larvae and juveniles remain to be determined. Current stocking densities will be very useful as starting point for more detailed studies and although optimum rearing densities are likely to be site-specific, replicated studies on density will provide a valuable reference for hatchery managers.

Frequency of sorting is another area that needs further research. Frequent handling and sorting can cause stress-related reductions in growth, but not sorting can create dominance hierarchies that further reduce growth rates of subordinate individuals. The effects of sorting on overall fish growth in both pond and intensive culture environments warrant further investigation. Research techniques for these types of experiments are well understood and typically utilize a matrix of replicate ponds per variable (Bays et al. 2005). In every case accurate and complete records of sampling procedures and data collection are needed in order to interpret data and make inferences about growth rates (Busacker et al. 1990).

Additional research is also needed to evaluate long-term survival of stocked fish reared in ponds compared to fish reared in intensive culture facilities. Exercise conditioning and predator-recognition training may also increase survival of stocked fish and be more economically feasible than rearing fish to increasingly larger sizes prior to stocking. The success of traditional fish hatchery programs is measured largely by the number of fish stocked, but hatchery programs for endangered species must measure success in terms of long-term survival and species recovery (Brannon 1993, Anders 1998). A specific list of research recommendations follows.

Specific Research Recommendations

- **Use replicated studies to establish optimum stocking densities for ponds and tanks that can be used as a starting point for site specific refinement**
- **Determine if sorting/grading improves overall growth rates in both ponds and intensive culture facilities**
- **Investigate the use of artificial fertilizers to improve growth of both juvenile and adult razorback suckers in ponds**
- **Determine if the razorback sucker diet gives better growth rates than cheaper catfish or salmon feeds.**
- **Evaluate growth rates and production potential of new intensive culture methods such as large circular tanks**
- **Evaluate long-term survival of fish produced from raceways and circular tanks compared to fish reared in ponds**
- **Evaluate more effective means of treating fish diseases**
- **Evaluate factors other than size that may increase post-stocking survival such as exercise conditioning , predator recognition training, or rearing under more natural settings**

II. The Effect of Disease Treatments on Razorback Sucker Growth

Section Summary

Formalin, copper sulfate, potassium permanganate and salt are all chemicals commonly used to treat *Ichthyophthirius multifiliis* outbreaks in captive razorback sucker (*Xyrauchen texanus*). We exposed 190 juvenile razorback suckers (127 – 26 mm TL) to 5, 5-day treatments with each chemical to evaluate the effects these chemicals may have on growth. Fish grew an average of 23.5 mm TL during the month study period. Fish treated with formalin grew on average 29 mm TL (0.3 mm/day), while fish treated with copper had the lowest growth averaging 20 mm TL (0.21 mm/day). No significant differences in growth were observed among fish treated with any of the chemicals compared to untreated fish (p>0.05). Reductions in growth as a result of repeated chemical treatments are not likely the cause of differences in growth rates among facilities that raise razorback suckers. Repeated chemical treatments may have other impacts to overall fitness or long-term survival but these effects were not evident in our study.

Introduction

Preservation of razorback sucker (*Xyrauchen texanus*) currently depends on captive rearing and stocking programs until permanent solutions to factors that prevent wild recruitment are found. Low survival of stocked razorback suckers (Brooks 1986, Marsh and Brooks 1989, Marsh and Pacey 2005) has caused target sizes for stocked fish to steadily increase in efforts to reduce predation mortality (Marsh et al. 2005, Schooley and Marsh 2007). Rearing fish to larger sizes at hatcheries comes with increased costs and creates the need to evaluate husbandry and rearing practices that may affect fish growth.

Formalin, copper sulfate, potassium permanganate and salt are all chemicals commonly used at razorback sucker rearing facilities to treat outbreaks of the protozoan parasite *Ichthyophthirius multifiliis*. "Ich" is one of the most pathenogenic diseases of cultured freshwater fishes (Matthews 2005) and causes large losses in captive populations of endangered razorback sucker. Each of these chemicals used to treat Ich only kill the free-swimming life stage of the parasite, requiring repeated doses over several days depending on water temperature. These chemicals treatments are needed to prevent loss as a result of disease outbreaks, but the cumulative effects repeated disease treatments have on growth are unknown.

Copper sulfate has been shown to significantly reduce growth of channel catfish in production ponds (Rabago-Castro 2006), but it is unknown whether razorback suckers experience similar reduced growth following copper treatment. Quantifying the impacts of disease treatments on growth will help to interpret the wide differences in growth rates observed at various razorback sucker production facilities throughout the southwest (Ward et al. 2007). If one chemical is found to have less detrimental impacts on growth than another then it may be preferred for use as a disease treatment. We evaluated growth rates of razorback suckers under replicated and controlled conditions to assess effects of repeated formalin, copper sulfate and potassium permanganate and salt treatments on growth.

Methods

We captured 190 juvenile razorback suckers from ponds at Bubbling Ponds Fish Hatchery, AZ using hoop nets or cast nets. All fish were of the same age class and averaged 179 mm total length (TL) (range = 127 – 262 mm TL). These fish were offspring of captive razorback sucker broodstock held at Dexter National Fish Hatchery, NM. (2007 year class). All fish were tagged with passive integrated transponder (PIT) tags and quarantined for one month prior to the experiment to allow fish to recover from tagging and become accustomed to being held in circular tanks.

At the beginning of the study all fish were weighed, measured and scanned for individual tag numbers with 19 randomly selected fish placed into each of 10, 8-foot diameter circular tanks (Figure 2). Each tank contained two airstones and an individual biofilter with a recirculating water pump (31 liters/minute) that had been operating for at least 1 month prior to the experiment to allow bacterial colonies to become established. Two tanks were designated as a control and did not receive any chemical treatments while the other eight tanks received formalin, copper sulfate, potassium permanganate, or salt treatments at two week intervals (two tanks per chemical treatment). Formalin, copper sulfate and potassium permanganate were treated at 1 part per million (ppm) and salt was applied at 3.0 parts per thousand (ppt). These treatment rates are commonly used to treat razorback suckers for ich at Bubbling Ponds Fish hatchery (Frank Agygos, personal communication).

Figure 2. Photo of experimental tanks with individual biofilters and aeration.

Each treatment consisted of a series of doses applied on Wednesday, Thursday and Friday with a 90% water change between each dose. Biofilters were removed from all tanks and held in a separate holding facility during treatments and then replaced on the Monday following treatments after a 90% water change. This schedule allowed fish to be exposed to chemical treatments for 5 consecutive days without water quality deteriorating. This 5-day chemical treatment was repeated every two weeks from July to October (97 days) for a total of 5, 5-day treatments. Water temperature in the treatment tanks ranged from 13°C (55°F) to 32°C (91°F).

Fish were fed a fixed ration of commercial razorback diet (Silvercup, 4mm pellet) once daily (2 % percent body weight per day as calculated by average initial fish weight). At the end of the experiment all fish were again weighed, measured and scanned for individual tag numbers. Growth of fish in each treatment group was compared using analysis of variance (ANOVA). Any mortalities that occurred during the study were replaced with previously quarantined fish of equivalent size to maintain equal densities in each tank, but growth data was only recorded for fish which survived the entire experiment.

Results

Fish at the start of the experiment averaged 179 mm TL (Range = 127 – 262 mm) with no significant differences in fish length among treatment groups ($F(4,189) = 0.0183$, $p > 0.999$ ANOVA). On average fish grew 23.5 mm TL (0.24 mm/day) during the 3 month study. Fish in tanks treated with formalin had the highest growth averaging 29 mm TL (0.3 mm/day) while fish in tanks treated with copper had the lowest growth averaging 20 mm TL (0.21 mm/day). Fish in the control tanks averaged 21.3 mm TL in growth (0.22 mm/day) (Figure 3). Formalin-treated fish grew significantly faster than any other treatment group, but no significant differences in growth in length or weight were observed among fish treated with any of the chemicals compared to untreated (control) fish ($p>0.05$, ANOVA).

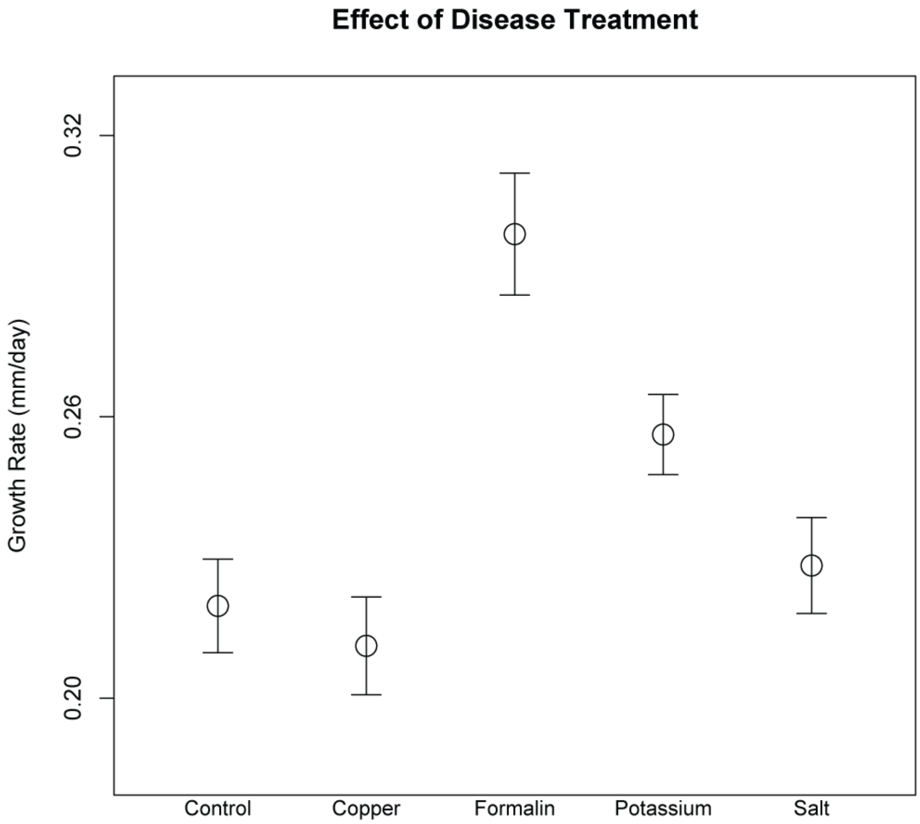


Figure 3: Average growth of razorback suckers exposed to a series of 5, 5-day chemical treatments over a 97-day period. Error bars represent standard error.

Discussion

Growth rates observed in our study (0.21 – 0.3 mm/day) are low compared to those reported in other studies of razorback sucker growth (0.2 – 1.8 mm/day) (Ward et al. 2007). Using recirculating water systems for our study required filters to be removed and replaced during treatments. Stress to fish caused by removing and replacing filters within the tanks as well as repeated water changes may have led to overall higher stress and reduced growth rates compared to those reported for unconfined fish. Growth in fish is highly variable and is affected by many different physiological and environmental factors including fish size, density, temperature, amount of space, and food (Brett 1979). We strived to control each of these factors, but other factors may have also influenced growth in our experimental tanks. During mid-summer, water temperatures in the treatment tanks reached 32°C (91°F). At these warm temperatures fish are very susceptible to bacterial infections. The slightly higher growth exhibited by fish in the formalin and potassium permanganate treatments may have been the result of these two chemicals being effective at controlling bacterial infections. The differences in growth we measured among treatment groups were not statistically significant and do not appear biologically meaningful during the relatively short duration of this study (97 days), although the cumulative effects of slightly reduced growth could be biologically meaningful over longer time frames.

Reductions in growth as a result o repeated chemical treatments are not likely the cause of differences in growth rates among facilities that raise razorback suckers. Repeated chemical treatments may have other impacts to overall fitness or long-term survival but these effects were not evident in our study. It is more likely that the parasite outbreaks themselves are the cause of different growth rates among razorback rearing facilities rather than the chemical treatments used to treat the parasites. We recommend that hatchery managers continue to use the chemicals that are most effective at controlling "Ich" at their individual facilities.

Acknowledgements

Funding for this project was provided by the U. S. Bureau of Reclamation in partial fulfillment of a cooperative agreement with the Lower Colorado Rive Multi-species Conservation Plan under Work Task C10. We thank Ty Wolters and Tom Burke for their support of this research and Frank Agygos and Dave Billingsly of the Bubbling Ponds Fish Hatchery for their technical assistance and help with collecting fish.

III. Razorback Growth Rates at Bubbling Ponds – 2009-2011

Section Summary

Experimental studies at Bubbling Ponds Fish Hatchery, AZ have strived to understand factors that affect razorback sucker growth in captivity and identify ways to improve growth rates and maximize size at release. Rather than performing experimental studies that would require major rearrangement (and likely reduced production) of hatchery operations, our studies used normal variation in production techniques and practices to isolate factors that may modify growth rates.

Our initial work identified razorback growth rates in lined ponds at standard fish density as 0.26 to 0.28mm/day (7.89 to 8.43 mm/month). No significant differences in growth rate were observed among fish that had been in the pond only during the winter period compared to fish that had been in the pond the entire year, indicating that water temperatures at Bubbling Ponds are high enough to allow fish to incorporate feed effectively year-round. However, these growth rates are lower than most values reported from the literature from natural or semi-natural pond environments. No significant differences in growth rate were observed between large and small fish within the 150 – 29 mm TL size range. Additional work suggests that razorback suckers tagged at over 300 mm TL had reduced growth rates (0.24 mm/day, 7.3 mm/month) as would be expected according to a typical Von Bertalanfy growth curve, although growth rates were only slightly less than the average growth rate for the hatchery (0.275 mm/day, 8.25 mm/month).

Sorting to separate small fish from large fish after the first year of growth is practice designed to allow smaller fish to "catch up" to larger fish. We found that this technique does appear to improve growth rates of smaller fish. Growth rates of sorted small razorback suckers (0.29 mm/day, 8.7mm/month) were equal to that of larger fish (0.28 mm/day, 8.4 mm/month) indicating that sorting may have helped to offset their original slower growth trajectory.

Bubbling Ponds Fish Hatchery grows razorbacks in 6 long, deep ponds lined with heavy plastic, 2 long, deep earthen (unlined) ponds, and three wide, shallow earthen ponds. The wide, shallow ponds have historically produced very large fish at low density, but have been found to maintain much lower fish numbers than deeper ponds. We found that growth rates of razorbacks kept at high density (4-7000 fish) in a wide, shallow pond grew extremely slowly (0.24 mm/day, 7.26 mm/month). This growth rate is among the slowest of any fish over the years of our study, and demonstrates that though the large ponds may produce large fish at low density, they are unable to overcome high fish densities.

Finally, one of the major factors influencing fish growth in hatcheries is disease; one major summer-time disease at Bubbling Ponds is the ectoparasite Ich (*Ichthiopthirus multifiliis*). To investigate the impact Ich has on razorback growth, we eradicated fish from the spring and water conveyance ditch that supplies water to the hatchery using Rotenone. This restoration effort was fairly short-lived (Ich returned to the hatchery within four months), but growth rates of fish reared for four months without Ich present (0.31 mm/day, 9.2 mm/month) were significantly higher than the following 8 months of growth for those same fish (0.22 mm/day, 6.5 mm/month). This disease-free growth rate is, in fact, faster than any other previous growth rates observed at the hatchery in our study.

We conclude that growth rates at the Bubbling Ponds Fish Hatchery are likely as high as possible given the pond densities required to meet production goals and the Ich-infested water that feeds the facility. Sorting practices are successful in helping as many fish as possible reach stocking length as fast as possible. Unlined ponds may be able to grow large fish at low densities, but whatever factors allow for that growth are not able to overcome high fish density. Thus, the large lower ponds at Bubbling Ponds may be better utilized via renovation to deepen and line them.

Disease is the most important factor limiting growth, as may be expected to be the case at many hatcheries. While the spring renovation was not a complete success, the dramatic reduction of fish populations in that habitat was enough to dramatically reduce the occurrence of Ich at the hatchery. Such open spring systems feeding a hatchery are a misfortune that can be expected to transmit disease, so we suggest that renovating the spring again to combat Ich. Improved techniques to divert water from the springs and more throuough treatment of stream-side vegetation may improve the success of chemical treatment. Successful renovation would likely both improve growth rates and reduce chemical costs associated with treating Ich outbreaks. Even if complete renovation is impossible or impractical, an effort to reduce invasive fish density in the springs which act a vector for the parasite(and thereby reduce the likelihood of Ich being transmitted into ponds) may still show dramatic improvements.

Introduction

Conservation efforts for razorback sucker (Xyrauchen texanus) currently depend on captive rearing and stocking programs. Low survival of stocked razorback suckers (Brooks 1986, Marsh and Brooks 1989, Marsh and Pacey 2005) has caused target sizes for stocked fish to steadily increase in efforts to reduce predation mortality (Marsh et al. 2005, Schooley and Marsh 2007). Rearing fish to larger sizes at hatcheries comes with increased costs and creates the need to evaluate husbandry and rearing practices that may affect fish growth. We evaluated growth rates of individual razorback suckers in ponds at Bubbling Ponds Fish Hatchery using Passive Integrated Transponder (PIT) tags to obtain precise growth information for individual fish so that valid comparisons of growth rates as related to rearing practices can be made.

Due to the critical nature of the razorback sucker stocking program, we did not design experimental studies that would require major rearrangement and potentially reduce production of hatchery operations. Instead, our studies used normal variation in production techniques and practices to isolate factors that may modify growth rates. Though this methodology dramatically limits replication and may limit our ability to directly attribute differences in growth rates to the variables we investigate, we were able to accomplish research goals without altering hatchery operations or impacting production.

From 2009 through 2011 we conducted a series of observational growth studies to determine growth rates of individual razorbacks at Bubbling Ponds. The first set of experiments included identifying growth rates in lined and unlined ponds, determining growth rates of fish at different sizes in relation to sorting practices, and monitoring razorback growth rates after removing the source of the ectoparasite Ich (*Ichthiopthirus multifiliis*) from the hatchery water source.

Razorback growth rate in lined ponds

Our first growth study documented individual growth rates at normal density in 1.1 million gallon lined ponds over two years. This is the standard grow-out process for razorbacks at Bubbling Ponds. We monitored growth of fish for a variety of sizes and the amount of time in a pond during the growing season. These data give a snapshot of growth rates at the facility and provide the basis for comparisons throughout our study.

Growth rate in an unlined pond

In addition to 6 ponds lined with heavy plastic sheeting, Bubbling Ponds Fish Hatchery maintains two narrow and deep (same dimensions as lined ponds, Figure 4) and three large, shallow unlined ponds. These earthen ponds typically have vegetation and associated aquatic invertebrates that may better simulate natural environments by providing cover and improved food diversity or quality. Therefore, these unlined ponds may be expected to produce higher growth rates and potentially improved survival that is more similar to growth rates observed in more natural grow-out facilities. Historically, the large, shallow ponds have produced very large fish when utilized at low fish density. The narrow, deep earthen ponds are used to grow fry at high density in their first year of life. The major downside to unlined ponds is the difficulty in harvesting fish; where a lined pond might take 8-10 people a half day to harvest, lined ponds require intensive weeding to allow seines to be pulled and therefore require many more personnel-hours. In addition to harvest challenges, the shallow earthen ponds tend to suffer from dissolved oxygen crashes during the summer. Unlined ponds also may maintain higher populations of non-target species such as bluegill sunfish, mosquito fish, and bullfrog tadpoles. We measured growth rates of suckers in a large, shallow earthen pond for comparison to growth in lined ponds.

Figure 4. Lined and earthen ponds of similar dimensions (approx 1,000,000 gallons, first and second panels) and a large, shallow earthen pond (third panel).

Effect of sorting on growth

Razorback suckers are currently sorted after their first year of growth. They are typically removed from one of the upper earthen ponds and split into two lined ponds for subsequent grow-out. The larger fish (> approximately 140 mm) are placed into one pond and the smaller individuals in another. It is possible that the larger fish were more aggressive or adept at taking food, so this sorting process is intended to allow smaller fish to improve their growth rate.

Effect of Ich on razorback sucker growth rates

We evaluated growth rates of razorback sucker in the presence and absence of the ectoparasite Ich (*Ichthiopthirus multifiliis*). Ich outbreaks can occur in wild populations, but hatcheries have proven excellent locations for Ich because of very high fish densities, which facilitate the transfer of Ich between fish This common fish parasite causes direct mortality to razorback suckers as well as secondary bacterial infections.

The open spring and ditch, which provides water to the Bubbling Ponds Hatchery, has long been infested with mosquitofish (*Gambusia affinis*) that harbor the Ich parasite and allow it to enter the hatchery with incoming water. The solution to the Ich problem was to remove the mosquitofish host using Rotenone. Razorback sucker growth rates were then tracked in the absence of this parasite for 4 months and compared with growth rates after Ich returned to the pond and from previous years.

Methods

Razorback growth rate in lined ponds

On May 14, 2008, 141 razorback suckers were tagged with 12 mm PIT tags (134.2 kHz) and placed in Pond 3 (approximately 1,100,000 gallons, Figure 4) at Bubbling Ponds Fish Hatchery. Fifty-three of these tags were recovered two months later when a large *Ichthyophthirius multifilis* (Ich) outbreak killed many fish in the pond. On October 15, 2008 an additional 145 PIT tagged fish were also placed into Pond 3. On May 14, 2009 Pond 3 was harvested and a total of 141 PIT tagged fish were recovered. Of the tagged fish, 26 fish had been in the pond since May of 2008 (378 days o growth) and 115 had been in the pond since October 15, 2008 (211 days of growth). Numbers of fish in Pond 3 after the Ich outbreak and for the majority of the period of growth were between 3, 000 and 4,000 fish. A Hobotemp® temperature logger was also installed in Pond 3, one meter below the water surface near the outflow and recorded water temperature every 3 hours to allow analysis of the effects of water temperature on growth rate (Figure 5). This Hobotemp data is representative of other pond temperatures throughout this study.

In a second experiment, 210 adult razorback suckers were PIT tagged on May 14, 2009 and placed into Pond 3 upper to evaluate growth rates of larger razorback suckers at Bubbling Ponds Hatchery under current rearing conditions. Size of these fish at tagging was (mean = 285 mm, range = 205 – 396 mm). These fish remained in the pond for 257 days and were harvested on Jan 25, 2010 to provide information on growth rates of larger razorback suckers under current rearing conditions.

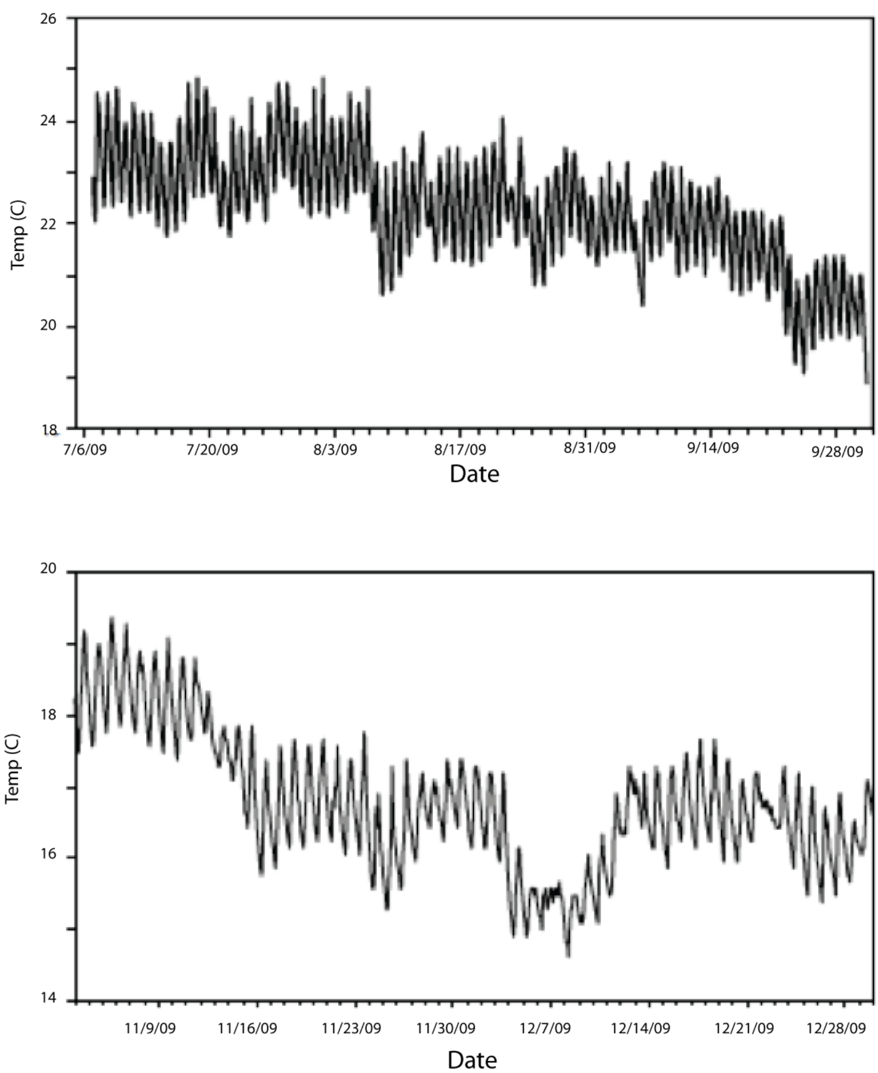


Figure 5. Temperatures (°C) in rearing pond at Bubbling Ponds Hatchery from July to Sept 2009 (top graph) and from Nov to Dec 2009 (Lower graph). Temperatures recorded with a Hobotemp® remote data logger every 3 hours.

Growth rate in an unlined pond

To document razorback sucker growth in earthen ponds, we introduced 225 tagged razorback suckers into Pond 1 lower (Figure 4) in February 3, 2010. Additional tagged fish from other studies were added to the pond throughout the growing season, and the density of 1 lower reached a maximum of nearly 7000 fish in early summer 2010. Density was reduced to approximately 6000 fish by capturing fish with hoop nets on June 3, 2010; 54 of these fish were tagged fish and returned to 1 lower after being weighed and measured. The pond was harvested on January 27, 2011 and a total of 254 tagged fish out of 4,296 fish total were removed from the pond. The pond was harvested on January 27, 2011 (358 days of growth) and the tagged fish were weighed and measured. Total number of razorbacks in the pond at harvest was 4,296.

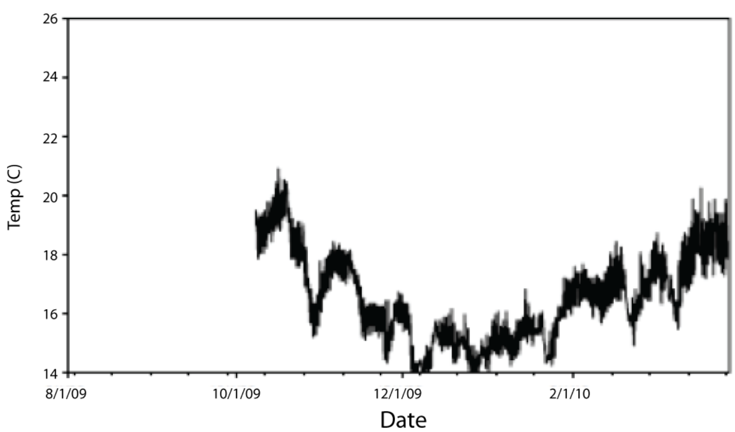
Effect of sorting practices on growth rates

On March 11, 2009, Pond 5 upper was harvested and split into two separate groups. Two hundred of the smaller fish (average size = 122 mm TL) were PIT tagged and placed into Pond 7 upper and 200 of the larger fish (average = 160 mm TL) were PIT tagged and placed int Pond 8 upper. Density in Pond 7 was 4,500 fish and in Pond 8 there were 6,500 fish. These ponds were then harvested after 1 year and growth rates were compared to give information on the effects of current sorting practices. Hobotemp® temperature loggers were installed in Ponds 7 and 8 during the grow-out period with water temperature recorded every 2 hours (Figure 6).

Effect of Ich on razorback sucker growth rates

Bubbling Ponds spring was treated with Rotenone (CFT Legumine, 5%) at a concentration of 2 ppm to remove all mosquitofish from the spring. The treatment consisted of two treatments, 6 hours in duration, on two consecutive days (April 12 - 13) using drip stations and backpack sprayers, followed by an additional 6 hours of detoxification using sodium permanganate. Although 12 mosquitofish were captured in the spring pond the week following the treatments, subsequent minnow trapping (20 traps checked daily for 3 weeks) did not capture any additional fish until August 11, 2010 when juvenile mosquitofish were again detected in the spring pond. Minnow traps have subsequently been set daily with several hundred individuals removed. To evaluate if Ich was also again present in the spring we captured 15 mosquitofish from the spring pond on three separate days and placed them in an aquaria at 25 °C with 5 longfin dace known to be free of Ich. These fish were monitored for 2 weeks with no signs of Ich developing. This indicates that even though mosquitofish have returned to the spring pond the parasite is no longer present, although how long this condition will persist is unknown.

On May 11, 2010, 200 juvenile razorback suckers were harvested out of Pond 5 upper (2009 year Class from Dexter National Fish Hatchery) and were PIT tagged and placed into Pond 8 to evaluate if growth rates at bubbling ponds hatchery have improved following the renovation of the spring and the removal of the Ich parasite. Unfortunately, on Sept. 8, 2010, Ich was again detected in Pond 8 and the pond was immediately seined and 74 tagged fish were measured to obtain growth information for the 4-month period during which the pond was Ich-free.



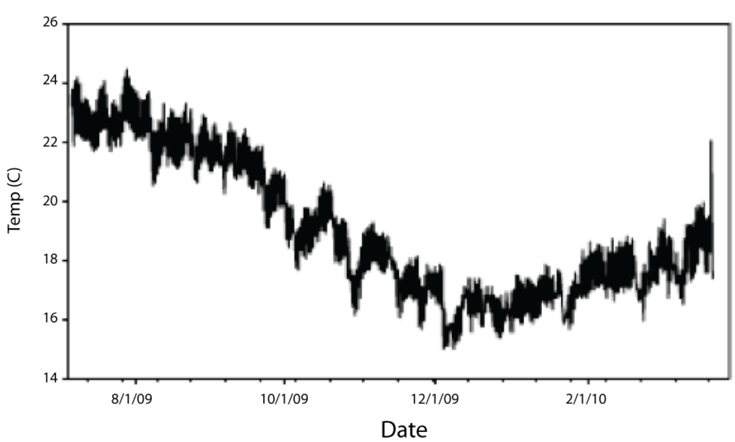


Figure 6. Temperatures (°C) in rearing ponds 7 and 8 at Bubbling Ponds Hatchery from March 2009 – March 2010, pond 7 (top graph) and pond 8 (Lower graph). Temperatures recorded with a Hobotemp® remote data logger every 3 hours.

Results

Growth in Lined Ponds

Razorback suckers that had been in Pond 8 upper for the entire year grew an average of 0.263 mm/day (7.89 mm/month), and razorback suckers that had been in the pond for 7 months (Oct. - May) grew on average of 0.28 mm/day (8.43 mm/month) (Figure 7). These growth rates did not significantly differ. Fish density in Pond 3 during the majority of the growth period was 0.0032 – 0.0036 fish/gallon. Additionally, no significant differences in growth rate were observed between fish smaller than 210 mm TL and fish larger than 210 mm TL when all recaptured fish were combined.

We also measured the growth rate of very large fish in a lined pond. On Jan 25, 2010, 156 adult fish with PIT tags were recovered from Pond 3 upper. These fish were in the pond for 257 days and experienced an average growth rate of 0.24mm/day or 7.3 mm/month (Figure 7). This growth rate is slightly lower than the average growth rate observed at Bubbling Ponds Hatchery in other studies (0.275 mm/day, 8.25 mm/month), but may not be biologically meaningful. We would expect larger fish to have reduced growth rates according to a typical Von Bertalanfy growth model (Bertalanffy 1957), but it appears that over the size range we evaluated (300 - 450 mm TL) growth rates have not slowed significantly compared to that of smaller fish grown at Bubbling Ponds Hatchery. Growth of razorback suckers is known to slow as fish reach larger sizes but it appears this reduced growth rate may not really start to be biologically meaningful at Bubbling Ponds Hatchery until razorback suckers exceed 450 mm TL.

Growth in unlined ponds

Growth rates for the fish recaptured during the Pond 1 lower thinning (120 days in the pond) was 0.24 ± 0.03 mm/day (7.29 ± 0.90 mm/month) (Figure 8). Fish that were in the pond for nearly the entire year grew an average of 0.24 ± 0.01 mm/day (7.26 ± 0.27 mm/month). These growth rates are surprisingly the lowest measured growth rates for any part of our study, and differ significantly from every other measured growth rate except very large fish (Figure 9). Separating out large fish that were in the pond for the entire year makes no difference; fish that were added to the pond at TL <300 mm grew

0.244 ± 0.01 mm/day (7.33 ± 0.28 mm/month) and, and those with TL >= 300 mm at the start of the experiment grew 0.22 ± 0.03 mm/day (6.51 ± 1.01 mm/month).

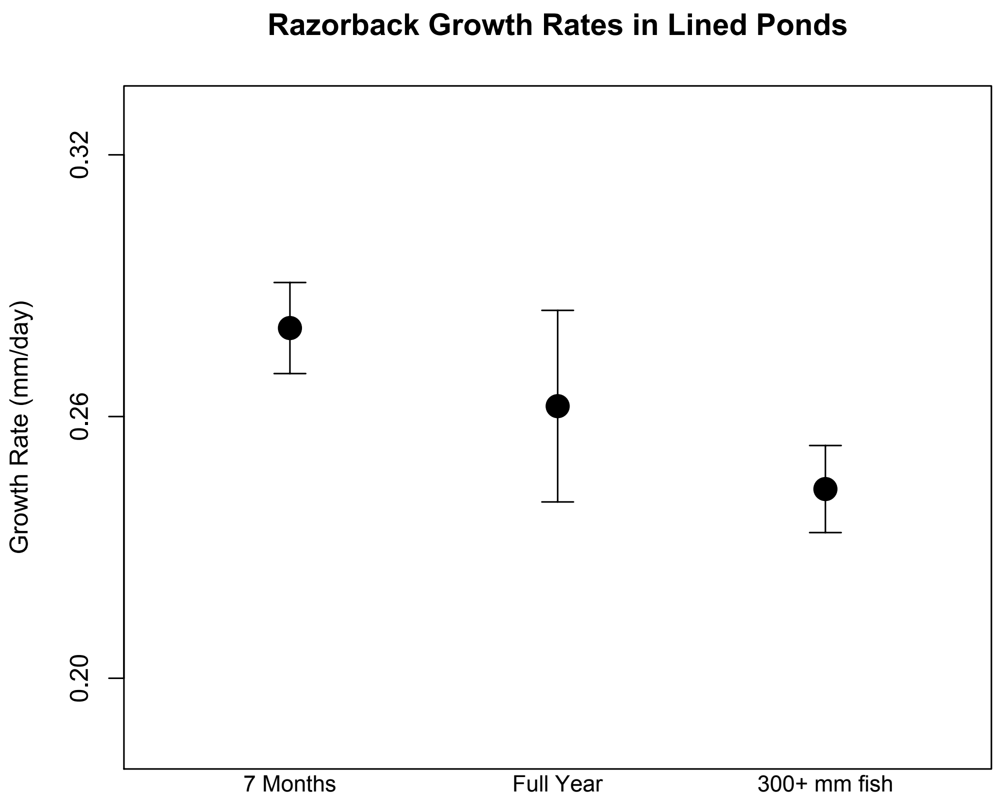


Figure 7. Growth of razorback suckers in (mm/day ± standard error) in Pond 8 upper in 2008-2009. An ANOVA did not detect any significant differences.

Effects of sorting on growth

One hundred and seventy five tagged razorback suckers were recovered from Pond 8 upper on March 24, 2010 (378 days of growth). These were the larger, sorted fish (>140 mm TL) that came out of Pond 5 on March 11, 2009. One hundred and twenty two tagged razorback suckers were also recovered from Pond 7 upper on March 31, 2010 (385 days of growth). These were the smaller, sorted fish (<140 mm TL) that came out of Pond 5 on March 11, 2009. No significant differences in growth rate (mm/day) were observed among larger fish in Pond 8 and smaller fish in Pond 7 ($p>0.05$, ANOVA) (Figure 10), indicating that sorting may have helped to offset the original slower growth trajectory of the smaller fish. Temperatures of Ponds 7 and 8 upper remained similar throughout the year (Figure 5).

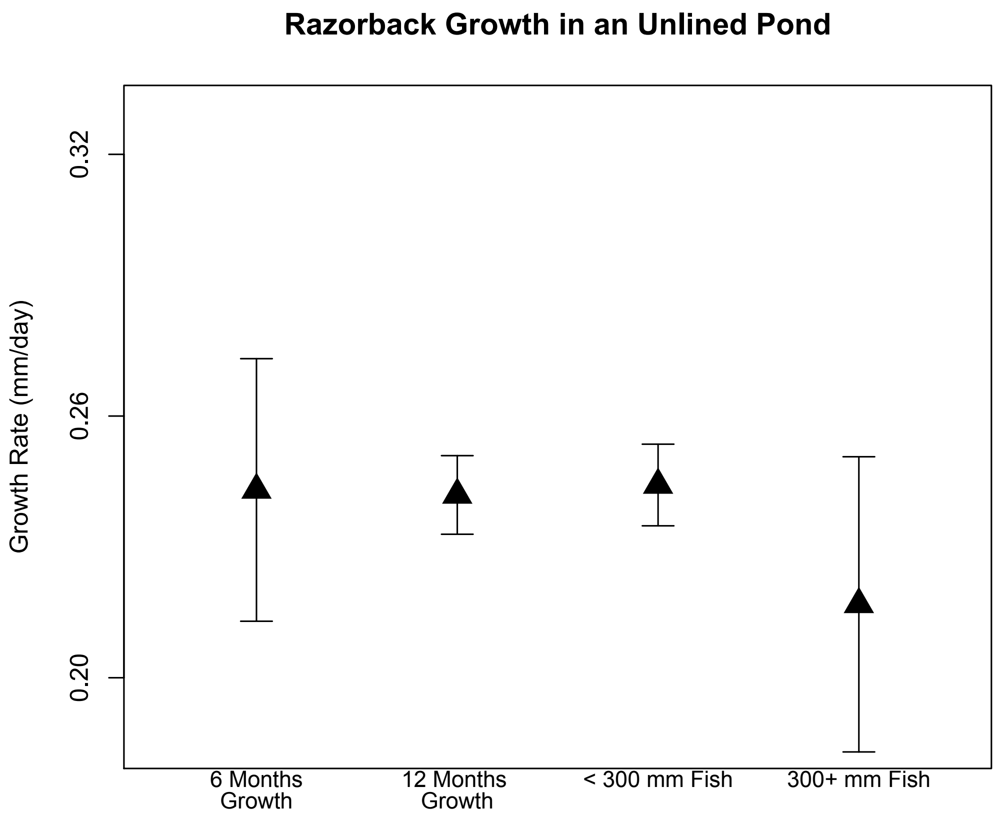


Figure 8. Growth of razorback suckers (mm/day ± standard error in Pond 1 lower (an unlined pond) in 2010-2011. An ANOVA did not detect any significant differences.

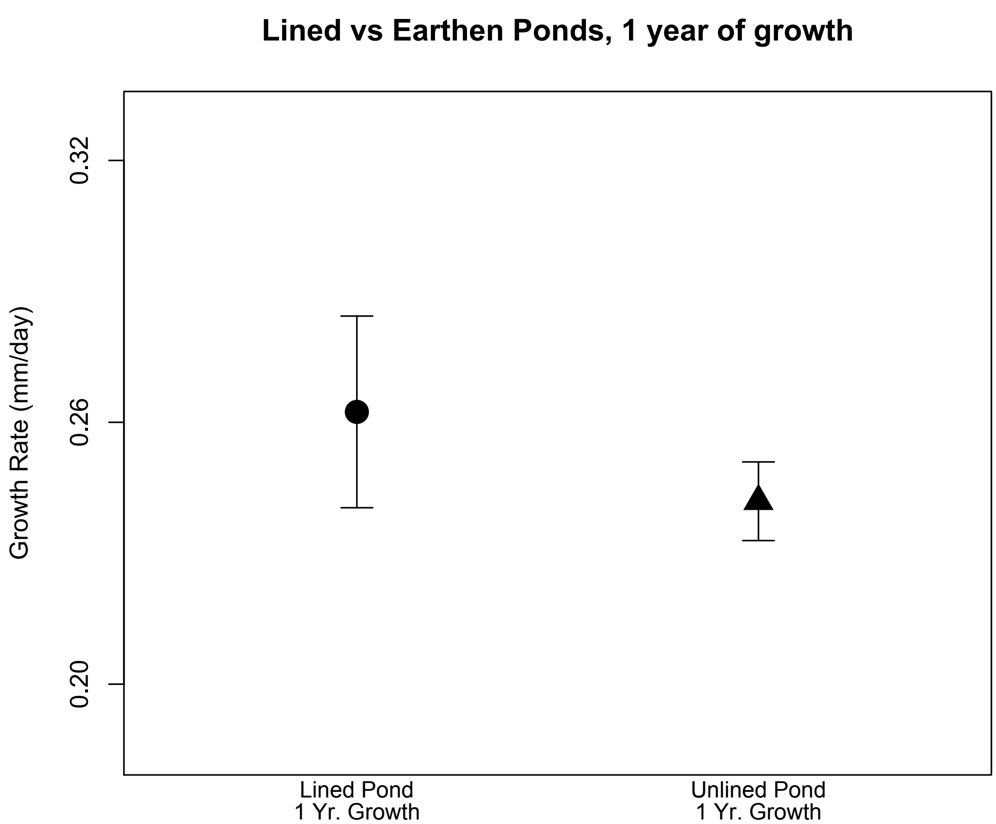


Figure 9. Growth of razorback suckers (mm/day ± standard error in lined and unlined ponds. A t-test did not detect a significant difference.

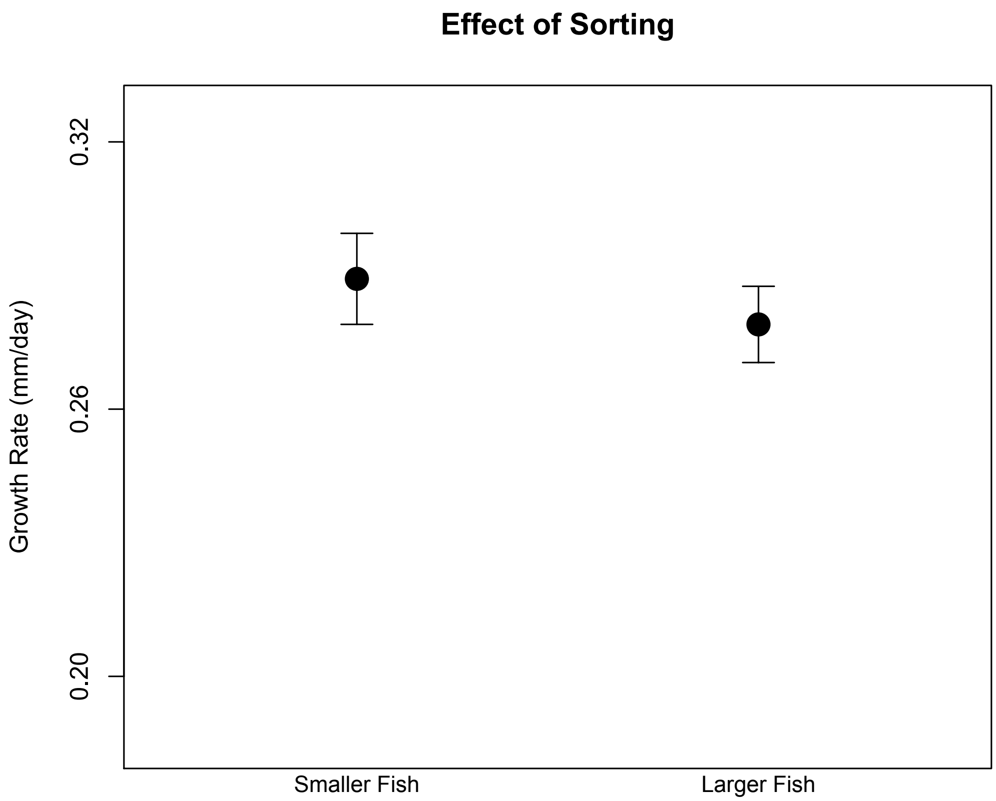


Figure 10. Average growth of razorback suckers (mm/day ± standard error) that were size-sorted into small fish (pond 7) and large fish (pond 8) populations. A t-test did not detect a significant difference.

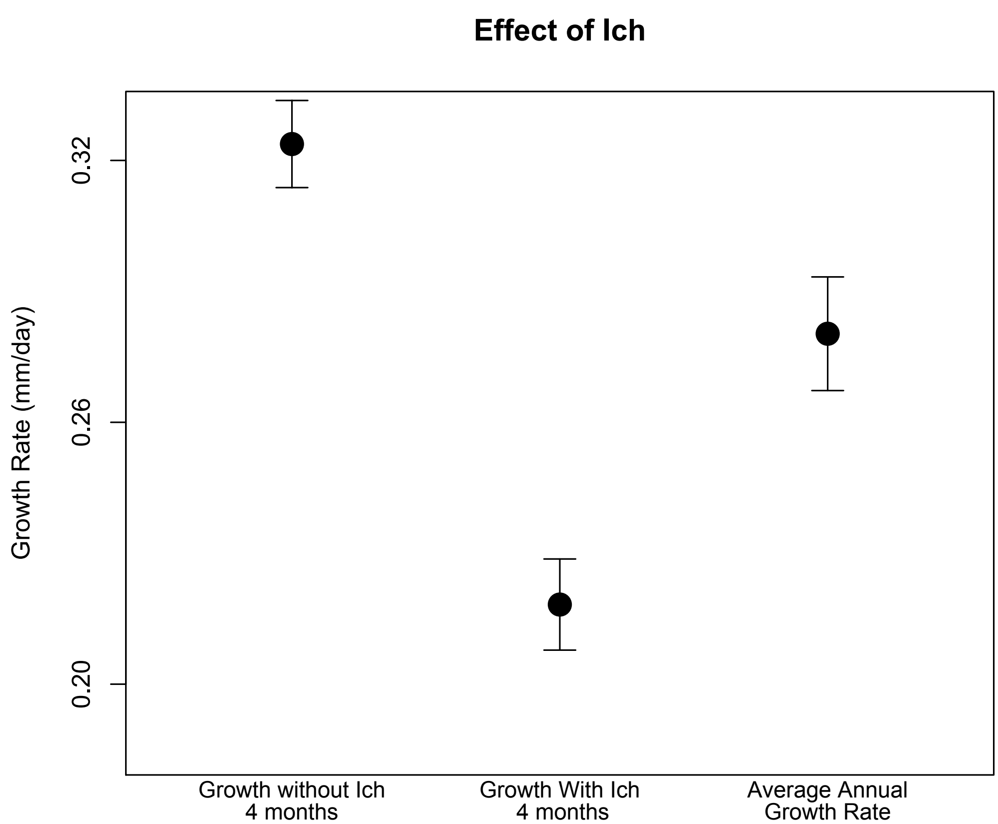


Figure 11. Average growth of razorback suckers (mm/day ± standard error) after Ich was removd from the hatchery's spring and after Ich was again detected in the pond. The growth rate without Ich is significantly higher than both the rate after Ich and the our study's average annual growth rate in lined ponds (ANOVA, p = 0.0003).

Effect of Ich on razorback sucker growth rates

Seventy-four tagged razorback suckers were recovered from Pond 8 on September 15, 2010. These fish had been in the pond for 4 months and experienced a growth rate of 0.32 mm/day or 9.7 mm/month (Figure 11). This growth rate is significantly higher ($p = 0.05$, two sample t-test) than the mean growth rate for the same group of tagged fish after Ich detection (0.22 mm/day or 6.5 mm/month), and significantly higher than any other individual growth rates observed to date at Bubbling Ponds Hatchery (Figure 11). If this growth rate were extended throughout the entire year, fish on average from Ich-free ponds would be 16 mm longer than fish from ponds infested with Ich. Studies conducted at Bubbling Ponds hatchery in 2008 (Ward 2008) did not reveal any effects of the treatment chemicals on razorback sucker growth rates, so it is likely that the parasite outbreaks themselves are causing reducing growth rates rather than the chemicals used to treat the parasites.

Conclusions

Our results suggest that under typical hatchery operations (maximizing number of fish produced) the growth rate of razorback suckers is relatively consistent at Bubbling Ponds hatchery at 0.2-0.3 mm/day (6-9 mm/month), but is lower than growth rates at other facilities (0.2 – 1.8 mm/day, Ward et al. 2007). This growth rate has been constant in both lined and unlined ponds and at all fish densities we were able to measure. To achieve growth rates substantially higher than this will likely require significant changes in rearing practices that may not be practical in order to reach numerical production goals.

Temperature is a key variable in fish growth, but seasonal growth patterns described above (Figure 5) demonstrate that water temperatures are high enough in winter to maintain razorback growth. Differences in water temperature by season currently do not fluctuate more than 10°C at Bubbling Ponds because of the continuous supply of water flowing through each pond (approx 225 gallons/min). These high water flows appear to keep pond temperatures within the thermal preference for razorback suckers (12 - 28 °C, Bulkley and Pimentel 1983) throughout the entire year with temperatures rarely dropping below 16° C (Figures 5, 6).

Fish density is another key variable in fish growth, and though the number of fish in a pond during our study ranged from 3000 to 7000 fish, we did not find any correlation between density and growth rate. This might yield two conclusions. First, razorback growth may be changed equally by densities at the hatchery (i.e. a density of 3000 fish in a pond is as stressful for razorbacks as a density of 7000 fish). An alternative is that other factors, such as disease outbreaks, have stronger control over fish growth than density. Fish density would have to be experimentally manipulated to test this, and hatchery operations (producing the maximum number of fish) prevented our manipulating density in ponds for this work. The trouble with manipulating density demonstrates the difficulties associated with changing hatchery practices: experimenting with density would have prevented BPH from meeting production goals. Given that the stocking of smaller razorbacks has met with very little success, perhaps BPH goals could be changed from producing 12,000 fish at 300+ mm per year to a smaller number of very large fish each year. Growing fewer, larger fish could potentially be accomplished in the same time frame as more, smaller fish, but a better understanding of how density alters growth rate would be required to be confident of this.

The very slow growth in the earthen, unlined Pond 1 lower was very surprising. We had anticipated that the diversified diet, cover, and other habitat features provided by unlined ponds would yield dramatically increased growth rates. However, these traits were not enough to offset high fish densities, and in fact the unlined pond in our study suffered mortality to bring densities down to that observed normally in lined ponds.

Our data suggest that razorbacks sucker growth rates are higher in lined ponds. However, we think the reasons for the very slow growth we observed in the unlined pond in our study is instead linked to the usage of Pond 1 lower during the study rather than intrinsic slow growth in earthen ponds. First, the pond was at extremely high density for at least part of the study. The volume of Pond 1 lower has not been estimated, but hatchery managers suggest 1500-2000 fish is an appropriate number of individuals, so this pond was at a very high density for much of the experiment. Second, dissolved oxygen is often very low in the large, earthen ponds during the heat of summer, much lower than that of lined ponds. This will both limit the number of fish that can survive in the pond and almost certainly increases stress of these fish, potentially reducing growth. The DO crashes also limit the amount of feed hatchery managers can give fish in these ponds, sometimes for days or weeks at a time, which further reduces growth during warm weather.

Our data suggests that growth rates at the Bubbling Ponds Fish Hatchery are likely as high as possible given the pond densities required to meet production goals and the Ich-infested water that feeds the facility. Sorting practices are successful in helping as many fish as possible reach stocking length as fast as possible. Unlined ponds may be able to grow large fish at low densities, but whatever factors allow for that growth are not able to overcome high fish density. The removal of invasive fis that act as a host for the parasite Ich fish from the Bubbling Ponds spring allowed the highest growth rate at 0.32 mm/day (9.6 mm/month), but that growth rate decreased again as Ich re-infested the hatchery. Consistently achieving growth rates as high or substantially higher than this will likely require significant changes in rearing practices that may not be practical in order to reach numerical production goals.

Two major changes that might result in higher growth rates are substantially reducing fish density and modifying the way spring water is delivered to the facility (via either repeated chemical treatments or enclosed, concrete water diversions) to eliminate Ich from the hatchery source water. Other potential changes not address by our work include flow-training razorbacks; much previous literature, including MSCP-funded work on razorback suckers, suggests that fish growing in flowing water will grow faster than fish in still water (Jorgensen and Jobling, 1994). Furthermore, there are a wide variety of potential benefits associated with growing fish in flowing water in addition to increased growth rates (Davidson, 1997; Castro et al. 2011). Another option for increasing growth rates include changing to intensive culture in large, circular tanks.

Finally, given that the stocking of smaller razorbacks has met with very little success, perhaps BPH goals could be changed from producing 12,000 fish at 300+ mm per year to a smaller number of very large fish each year. Growing fewer, larger fish could potentially be accomplished in the same time frame as more, smaller fish, but a better understanding of how density alters growth rate would be required to be confident of this.

Acknowledgements

Funding for this project was provided by the U. S. Bureau of Reclamation in partial fulfillment of a cooperative agreement with the Lower Colorado River Multi-Species Conservation Program (LCRMSCP) under Work Task C10. We thank Ty Wolters, Tom Burke, and Eric Volkman for their support of this research and Frank Agygos and Dave Billingsly of the Bubbling Ponds Fish Hatchery for their willingness to participate in this research and for their technical assistance. We also thank the LCRMSCP fish group from Boulder City, NV for their assistance with harvesting ponds and tagging fish.

Literature Cited

Anders. P. J. 1998. Conservation aquaculture and endangered species: can objective science prevail over risk anxiety? Fisheries 23(11): 28-31.

Anderson, R. O. and R. M. Nuemann. 1996. Length, weight, and associated structural indices. Pages 447 – 482 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edtion. American Fisheries Society, Bethesda, Maryland.

Bain, M. B., J. T. Finn, and H. E. Brooks. 1988. Streamflow regulation and fish community structure. Ecology. 69:382-392.

Bays J. H. Zarbock, R. Whitman, and T. Murphy. 2005. Conceptual design and management of native fish refugia on the lower Colorado River. In: C.L. Spring and S. Leon editors. Proceedings of two symposia. Restoring native fish to the lower Colorado River: interactions of native and non-native fishes. 13–14 July 1999, Las Vegas, Nevada. Restoring natural function within a modified riverine environment: the lower Colorado River. 8–9 July 1998. U. S Fish and Wildlife Service, Southwestern Region, Albuquerque, New Mexico. Pages 167-177.

Bertalanffy, L. Von 1957. Quantitative laws in metabolism and growth. Q. Rev. Biology 32: 217 – 231.

Bingham, T., B. Scheer, and C. McAda. 2003. Propagation facilities, in Grand Valley (24 Road Hatchery, Horsethief Ponds, and grow-out ponds) for captive rearing ofendangered fishes for the upper Colorado River basin. Colorado River RecoveryProgram, FY 2003 annual project report. U.S. Fish and Wildlife Service, GrandJunction. 4pp.

Birchell, G. J., and K. Christopherson. 2004. Survival, growth and recruitment of larval and juvenile razorback sucker (*Xyrauchen texanus*) introduced into floodplain depressions of the Green River, Utah. Final report. Upper Colorado River Endangered Fish Recovery Program Project No. C-6RZ. Publication Number 04-15. Utah Division of Wildlife Resources, Salt Lake City, Utah. 67 pages.

Brannon, E. L. 1993. The perpetual oversight of hatchery programs. Fishery Research 18: 19-27.

Brett, J. R. 1979. Environmental Factors and growth. pages 599-675 *In* W. S. Hoar, D. J. Randall, and J. R. Brett. (eds.). Fish Physiology. Volume 8. Bioenergetics and Growth. Academic Press, New York.

Brooks, J. E. 1986. Annual reintroduction and monitoring report for razorback sucker *Xyrauchen texanus*, in the Gila River Basin, Arizona, 1985. U.S. Fish and Wildlife Service, Offices of Endangered Species and Fishery Resources, Albuquerque. 23 pp.

Brunson, R. E., and K. D. Christopherson. 2005. Larval razorback sucker and bonytail survival and growth in the presence of nonnative fish in the Baeser floodplain wetland of the middle Green River. Final report prepared for Upper Colorado River Basin Endangered Fish Recovery Program, Project No. C-6-rz-bt. Publication No. 05-26. Utah Division of Wildlife Resources, Vernal. 32 pp.

Bulkley, R. V., and R. Pimentel. 1983. Temperature preference and avoidance by adult razorback suckers. Transactions of the American Fisheries Society. 112:601-607.

Burke, T. 1995. Rearing wild razorback sucker larvae in lake-side backwaters, Lake Mohave, Arizona/Nevada. Proceedings of the Desert Fishes Council. 26:35.

Busacker, G. P. , I. R. Adelman, and E. M. Goolish. 1990. Growth. Pages 363 – 387 *in* C. B. Schreck and p. B. Moyle, editors. Methods for fish biology. American Fisheries Society, Bethesda, Maryland.

Castro, V., B. Grisdale-Helland, S. J. Helland, T. Kristensen, S. M. Jorgensen, J. Helgrud, G. Claireaux, A. P. Farrell, A. Krasnov, and H. Takle. 2011. Aerobic training stimulates growth and promotes disease resistance in Atlantic salmon (*Salmo salar*) Comparative Biochemistry and Physiology - Part A: Molecular & Integrative Physiology 160(2): 278-290

Czapla, T. E. 2002. Facilities plan for the production of endangered fishes to meet state stocking plans as part of the Upper Colorado River Endangered Fish Recovery Program. Upper Colorado River Basin Recovery Implementation Program. U.S. Fish and Wildlife Service, Denver. 9 pp.

Davidson, W. 1997. The effects of exercise training on teleost fish, a review of recent literature. Comput. Biochem. Physiol. 117A:67–75

Figiel Jr., C. R. 2005. Annual report, fiscal year 2004. Willow Beach National Fish Hatchery, U.S. Fish and Wildlife Service, Willow Beach. 17 pp.

Figiel Jr., C. R., M. E. Ulibarri, G. Carmichael, J. Seals, and J. N. Hanson. 2005. Intensive fish culture of warmwater native fishes at a coldwater fish hatchery. Pages 164-166 *in* Proceedings of two symposia: restoring native fish to the lower Colorado River: interaction of native and non-native fishes. July 13-14, 1999. Las Vegas, Nevada. U.S. Fish and Wildlife Service, Southwest Region, Albuquerque, New Mexico.

Gerking S. D. 1978. Ecology of freshwater fish production. Halstead Press, New York.

Gustafson, W., and Q. Bradwisch. 2000. Wahweap operation and maintenance -- Utah. Colorado River Recovery Program, FY 2000 annual project report. Project No. 29c. Utah Division of Wildlife Resources. Page, AZ. 3pp.

Hamman, R. L. 1985. Induced spawning of hatchery-reared razorback sucker. Progressiv Fish Culturist 47(3): 187-189.

Hanson, J. N. 1996. Annual report fiscal year 1996. Willow Beach National Fish Hatchery, U.S. Fish and Wildlife Service, Willow Beach. 9pp.

Irving, D., S. Seversen, and M. Montagne. 2004. Operation and maintenance of Ouray National Fish Hatchery. Colorado River Recovery Program, FY 2004 annual project report. Report No. 29b. U.S. Fish and Wildlife Service, Vernal. 3pp.

Jorgensen, E. H., and M. Jobling. 1994. Feeding and growth of exercised and unexercised juvenile Atlantic salmon in freshwater, and performance after transfer to seawater. Aquaculture International 2: 154-164.

Kaeding, L. R., and D. B. Osmundson. 1989. Colorado Squawfish and razorback sucker grow-out pond studies as part of conservation measures for the green mountain and Ruedi reservoir water sales. Final report for agreement number 6-AA-60-00150.

Koebele, B. P. 1985. Growth and the size hierarchy effect: an experimental assessment of three proposed mechanisms: activity differences, disproportional food acquisition, pysiological stress. Environmental Biology of Fishes 12: 181-188.

Kretschmann, A. E., and L. L. Leslie. 2006. Razorback sucker (*Xyrauchen texanus*) status, reproduction, and recruitment in Senator Wash Reservoir, CA. Final Report to U.S Burea of Reclamation. Cooperative Agreement No. 00-FG-34- 0009., p. 32. Arizona Game and Fish Department, Phoenix.

Marsh, P. C. 1987a. Digestive tract contents of adult razorback suckers in Lake Mohave, Arizona-Nevada. Transactions of the American Fisheries Society. 116:117-119.

Marsh, P. C. 1987b. Native fishes at Buenos Aires National Wildlife Refuge and Arizona State University Research Park, Arizona: opportunities for management, research and public education on endangered species. Proceedings of the Desert Fishes Council. 19:67-78.

Marsh, P. C. 1994. Rearing native Colorado River fishes in golf course ponds. Arizona State University, Tempe. 22 + pages.

Marsh, P. C. 2000. Fish population status and evaluation in the Cibola High Levee Pond. Final report, agreement number 99-FG-30-00051. U.S. Bureau of Reclamation, Boulder City Nevada. 20 pages.

Marsh, P. C., and C. A. Pacey. 1998. Growth of wild adult razorback suckers in Lake Mohave, Arizona-Nevada. Final report. U.S. Bureau of Reclamation, Boulder City, Nevada. 25 pages + appendices.

Marsh, P. C. B. R. Kesner, and C. A. Pacey. 2005. Repatriation as s management strategy to conserve a critically imperiled fish species. North American Journal of Fisheries Management 25: 547-556.

Marsh, P. C., and C. A. Pacey. 2005. Immiscibility of native and non-native fishes. Pages 59-63 *in* M.J. Brouder, C.L. Springer, and C.S. Leon, editors. Proceedings of two symposia: Restoring native fish to the lower Colorado River: interactions of native and non-native fishes. July 13-14, 1999. Las Vegas, NV, and Restoring natural function within a modified riverine environment: the lower Colorado River. July 8-9, 1998. Las Vegas, NV. U.S. Fish and Wildlife Service, Southwest Region, Albuquerque, New Mexico.

Marsh, P. C., and J. E. Brooks. 1989. Predation by ictalurid catfishes as a deterrent to reestablishment of hatchery-reared razorback sucker. The Southwestern Naturalist. 34:188-195.

Matthews, R. A. 2005. Ichthyopthirus multifiliis Fouquet and Ichthyopthirosis in freshwater teleosts. Pages 159-218 in Advances in Parasitology, volume 59. J. R. Baker, R. Muller, D. Rollinson (eds). Academic Press.

McCarthy, M. S., and W. L. Minckley. 1987. Age estimation for razorback sucker (Pisces Catostomidae) from Lake Mohave, Arizona and Nevada. Journal of the Arizona-Nevada Academy of Science. 21:87-97.

Minckley, W. L. 1983. Status of the razorback sucker, *Xyrauchen texanus* (Abbot), in the lower Colorado River basin. The Southwestern Naturalist 28(2): 165-187.

Minckley, W. L. 1991. Native fished of the Grand Canyon region: an obituary? Pages 124-177 *in* Colorado River ecology and dam management. National Academy Press Washington, D.C.

Minckley, C. O., and M. LaBarbara. 1999. Report on native fish grow-out facilities at Cibola and Imperial National Wildlife Refuges 1993-1995. U.S. Fish and Wildlife Service, Parker Fishery Resources Office, Parker, Arizona.

Modde, T. 1996. Juvenile razorback sucker (Xyrauchen texanus) in a managed wetland adjacent to the Green River. Great Basin Naturalist. 56:375-376.

Modde, T., K.P. Burnham, and E. J. Wick. 1996. Population status of the razorback sucker in the middle Green River (U.S.A.). Conservation biology 10: 110-119.

Modde, T., and G. B. Haines. 2005. Survival and growth of stocked razorback sucker and bonytail in multiple floodplain wetlands of the middle Green River under reset conditions. Final report prepared for Upper Colorado River Basin Recovery Implimentation Program. U.S. Fish and Wildlife Service, Vernal. 66 pp.

Modde, T., Z. H. Bowen, and D. C. Kitcheyan. 2005. Spatial and temporal use of a spawning site in the middle Green River by wild hatchery-reared razorback suckers. Transactions of the American Fisheries Society. 134:937-944.

Mueller, G. 1992. The native fish work group - a multiagency endeavor to improve the status of the razorback sucker in Lake Mohave, AZ-NV. Proceedings of the Desert Fishes Council. 23:69.

Mueller, G. 1995. A program for maintaining the razorback sucker in Lake Mohave. American Fisheries Society Symposium. 15:127-135.

Mueller, G. 2006. Ecology of the bonytail and razorback sucker and the role of offchannel habitats in their recovery. Scientific investigations report 2006-5065. U.S. Geological Survey, Denver.

Mueller, G., and E. Wick. 1998. Testing of golf course ponds at Page, Arizona for suitability as grow-out facility for razorback sucker using surplus fish from Ouray National Fish Hatchery. National Park Service, U.S. Fish and Wildlife Service and Utah Division of Wildlife Resources. 28 pages. .

Mueller, G., and T. Burke. 2005. Survival of young razorback sucker (*Xyrauchen texanus*) in relation to stocking rates (fish/ha) and in the presence or absence of predator communities in Lake Mohave, Arizona-Nevada. Pages 155-163 in Proceedings of two symposia: restoring native fish to the lower Colorado River: interaction of native and non-native fishes. July 13-14, 1999. Las Vegas, Nevada. U.S. Fish and Wildlife Service, Southwest Region, Albuquerque, New Mexico.

Mueller, G., J. Carpenter, and P. C. Marsh. 2004. Cibola High Levee Pond annual report 2004. U.S. Geological Survey, Fort Collins Science Center, Colorado, and Arizona State University, Tempe. 23 pages.

Nesler, T. P., K. Christopherson, J. M. Hudson, C. W. McAda, F. Pfeifer, and T. E. Czapla. 2003. An integrated stocking plan for razorback sucker, bonytail, and Colorado pikeminnow for the Upper Colorado River Endangered Fish Recovery Program. Addendum to State Stocking Plans. Upper Colorado River Basin Recovery Implementation Program. 12 pp.

Papoulias, D., and W. L. Minckley. 1992. Effects of foo availability on survival and growth of larval razorback suckers in ponds. Transactions of the American Fisheries Society. 121:340-355.

Paukert, C. P., D. L. Ward, P. J. Sponholtz, and K. D. Hilwig. Effects of repeated hoopnetting on bonytail chub. Journal of Freshwater Ecology 20(4): 649-653.

Pfeifer, F., M. C. Baker, and M. Montagne. 1999. Propagation facilities, in the Grand Valley (24 Road Hatchery, Horsethief Ponds, and grow-out ponds), for captive rearing of endangered fishes for the Upper Colorado River Basin. Colorado River Recovery Program, FY 99 annual project report. Project No. 29a. U.S. Fish and Wildlife Service, Grand Junction. 5pp.

Pfeifer, F., S. Seversen, and M. Montagne. 2003. Operation and maintenance of Ouray National Fish Hatchery. Colorado River Recovery Program, FY 2003 annual report. Project No. 29b. U.S. Fish and Wildlife Service, Vernal. 4pp.

Rabago-Castro, J. L., Sanchez J. G., Perez-Castaneda R., and Gonzalez-Gonzlez A. 2006. Effects of the prophylactic use of Romet-30 and copper sulfate on growth, condition and feeding indicies in channel catfish (Ictalurus punctatus). Aquaculture 253: 343-349.

Reinitz, G.L. , L. E. Orme, and F. N. Hitzel. 1979. Variations of body compositio and growth among strains of rainbow trout. Transactions of the American Fisheries Society 108: 204-207.

Ruppert, J. B., P. B. Holden, and P. D. Abate. 1999. Age estimation and growth of razorback sucker, *Xyrauchen texanus*, in Lake Mead, Nevada. Proceedings of the Desert Fishes Council. 30:40.

Schnoor, K. D., and J. Logan. 2002. Operation and maintenance of J.W. Mumma native aquatic species restoration facility, Colorado. Colorado River Recovery Program, FY 2002 annual project report. Project No. 29d. Colorado Division of Wildlife, Alamosa. 3pp.

Salisbury, L. 1998. Factors affecting razorback sucker growth in Lake Mohave backwaters. M.S. Thesis, Unviersity of Nevada, Las Vegas.

Schooley J. D., and P. C, Marsh. 2007. Stocking of endangerdd razorback suckers in the lower Colorado River Basin over three decades: 1974-2004. North American Journal of Fisheries Management 27: 43-51.

Severson, S. H., H. M. Tyus, and G. B. Haines. 1992. An evaluation of feeds for raising razorback sucker, *Xyrauchen texanus*. Journal of Applied Aquaculture. 1:55-65.

Toney, D. P. 1974. Observations on the propagation and rearing of two endangered species in a hatchery environment. Proceedings of the Annual Conference of the Western Association of State Game and Fish Commissions. 54: 252-259/

Tyus, H. M. 1998. Razorback sucker (*Xyrauchen texanus*) recovery plan. University of Colorado, Center for Limnology, Boulder. 76 pages.

Tyus, H. M., and S. H. Severson. 1990. Growth and survival of larval razorback suckers fed five formulated diets. The Progressive Fish Culturist. 52:197-200.

Ulibarri, M. E. 2003. Annual report, fiscal year 2001. Dexter National Fish Hatchery and Technology Center, U.S. Fish and Wildlife Service, Dexter, New Mexico. 26 pages.

Ulibarri, M. E. 2003. Annual report, fiscal year 2002. Dexter National Fish Hatchery and Technology Center, U.S. Fish and Wildlife Service, Dexter, New Mexico. 59 pages.

USBR. 2006. Lower Colorado River Multi-Species Conservation Program: final fish augmentation plan. Boulder City. 19 pp.

USFWS 2002. Razorback sucker (Xyraouchen texanus) recovery goals: Amendment and supplement to the Razorback Sucker Recovery Plan: U.S. Fish and Wildlife Service, Region 6, Denver, Colorado.

USFWS. 1999. Annual report, 1999. Ouray National Fish Hatchery. Vernal. 25pp.

USFWS. 2004. Management plan for the big-river fishes of the lower Colorado river basin: amendment and supplement to the bonytail, humpback chub, Colorado pikeminnow, and razorback sucker recovery plans.

USFWS. 2005. Station profile of the Dexter National Fish Hatchery and Technology Center. U.S. Fish and Wildlife Service, Dexter.

Valdez, R. A., P. G. Mangan, R. Smith, and B. Nilson. 1982. Upper Colorado River fisheries investigations. *in* W. H. Miller, J. J. Valentine, D. L. Archer, H. M. Tyus, R. A. Valdez, and L. Kaeding editors. Colorado River Fishery Project, Part 2: Field investigations: U.S. Bureau of Reclamation, Salt Lake City, Utah.

WBNFH. 2004. Culture methods of the endangered razorback sucker Xyrauchen texanus. U.S. Fish and Wildlife Service, Willow Beach National Fish Hatchery. 8 pp.

Ward, D. 2008. Effects of disease treatments on growth of razorback sucker. Report Submitted to The Lower Colorado River Multi-Species Conservation Program In partial fulfillment of work task C10, agreement number 06FG30039.

Ward, D., M. Childs and W. Persons. 2007. Factors affecting growth of razorback sucker (Xyrauchen texanus) in captivity: Literature review and knowledge assessment. Report Submitted to The Lower Colorado River Multi-Species Conservation Program In partial fulfillment of work task C10, agreement number 06FG30039.

Appendices

Appendix 1. Survey Questions

Survey of Razorback Sucker Culture in the
Southwestern United States

The enclosed survey is being distributed by the Arizona Game and Fish Department to razorback sucker culture facilities throughout the Southwestern United States. The purpose of this survey is to consolidate information regarding culture of this species so that appropriate facility improvements can be considered for Bubbling Ponds Hatchery in Arizona. Specifically, we wish to increase growth rate and production efficiency at the hatchery. Information gathered in this survey will be summarized in a final report to U.S. Bureau of Reclamation in Boulder City, NV, and disseminated to all facilities that participate in the survey. A workshop to discuss the findings of this study, as well as to share general information concerning razorback sucker culture, will be organized by the Arizona Game and Fish Department at the conclusion of this study, and all participants will be invited.

Thank you for taking the time to fill out this survey. Please contact Mike Childs if you have questions or would like to discuss the survey.

Mike Childs
mchilds@sedona.net
(928) 639-1346
(928) 634-1279
Facility:_____________________________________ Date:___________________
Contact Phone # ____________________________
ContactPerson_______________________________
Contact Email: _______________________________

1. Water quality ranges at this culture facility.

Season				
	Spring (Mar-May)	Summer (Jun-Aug)	Fall (Sept-Nov)	Winter (Dec-Feb)
Temperature (C)				
PH				
D.O (mg/L)				
PO_4 (mg/L)				
TDS (mg/L)				
Hardness (mg/L) $CaCO_3$				
Pathogens				

2. What is the water source (spring, well, river, etc.) and is the source protected from fish and pathogen introduction?

3. Holding facilities available for razorback sucker.

Type[1]	N	Vol (ft^3)	Flow (gpm)	Max weight 4 inch fish	Max weight 6 inch fish	Max weight 8 inch fish	Max weight 10inch fish	Max weight 12inch fish	Max weight 14inch fish

[1]Type: (EP) denotes earthen pond, (LP) lined pond, (LR) linear raceway, (CT) circular tank, and (AQ) aquarium

4. Do you try to maintain density and flow indices at a constant value? If not, what do you think the ideal density and flow indices are for your facility?

5. Feeding and growth of razorback sucker.

Average Fish Length	Food and Quantity (g food/kg Fish)[1]								Average Growth Rate (in/month)
Larvae									
2 inch									
4 inch									
6 inch									
8 inch									
10 inch									
12 inch									
14 inch									
16 inch									

[1]Food types include: TS (trout starter), T1-5 (trout chow 1 –5), CS (catfish starter), C1-5 (catfish 1-5), RS (razorback starter), R1-5 (razorback 1-5), A (Artemia), K (krill), B (bloodworm); include notes for other food types.6. What factors do you think would be most important in improving growth rate of razorback sucker at your facility? Please discuss factors such as water quality (temperature, oxygen, pH, nitrogen), fish density, flow rate, food type and quantity, photoperiod, reproductive condition, etc., as they pertain to your facility.

7. Do you have problems with razorback stunting (or variable growth rates) at your facility? What factor(s) do you think contribute most to stunted growth of razorback sucker at your facility?

8. Do you think that natural variation in growth rate of razorback sucker can be overcome by manipulating any factors at your facility? If so, at what cost (monetary, loss of genetic diversity, etc.)?

9. Based on your answers to the above questions, what do you think the ideal culture situation would be for razorback sucker if the primary management goal was to improve growth rate (culture container, water conditions, feed, etc.).

10. Do you have any data (electronic format) that you would be willing to share that could be used to compare growth rates of razorback sucker at the various culture facilities in the Southwestern United States? If so, accompanying data on water quality, fish density, etc., would add greatly to such a dataset. This information will be summarized and provided to all razorback culturists who participate in this survey.

11. Please provide a general history of razorback sucker culture at your facility (years of culture, strategies attempted). Please include successes and failures (with details regarding holding conditions, flow, etc.), and provide an explanation for what has worked and what has not.

Appendix 2. Follow-up Surveys

Questions about existing facilities

1. What is the biggest difficulty at your facility in growing subadult razorback suckers to the target size (300 mm)?

2. What diseases are most problematic at your facility?

3. How do you treat for these diseases?

4. Do you have a target stocking density for ponds? What is it?

5. What do you feed your fish?
   How many times a day do you feed?
   What % of body weight?

6. How often do you sort/or grade fish during the year?
   How are the fish graded?

7. How do you harvest fish?
   Drain ponds completely, seine a lowered pond, fyke nets, hoop nets etc.

8. How big are the fish that you normally start with?
   How big approximately are your fish at the end of the first year?
   How long approximately does it take you to grow fish to the target size (300 mm)?

9. Do you have temperature data or growth rate data for your facility and would you be willing to share it.

OR

10. Approx when does the mean water temp reach 20°C at your facility? Spring - Month. When in the fall does it begin to drop below 20°C.

Hypothetical questions - Opinions as to what you think would work best

1. In your opinion, what would be the best type of facility for growing out subadult RZB. (100 mm to 500 mm).

   Raceways
   Circular tanks
   Ponds
   Other

2. If using ponds, what size pond would be most effective?
   By surface area.
   1/10 acre .5 acre, 1 acre 10 acres etc.

3. What would be the ideal depth?
   Average depth
   Max depth

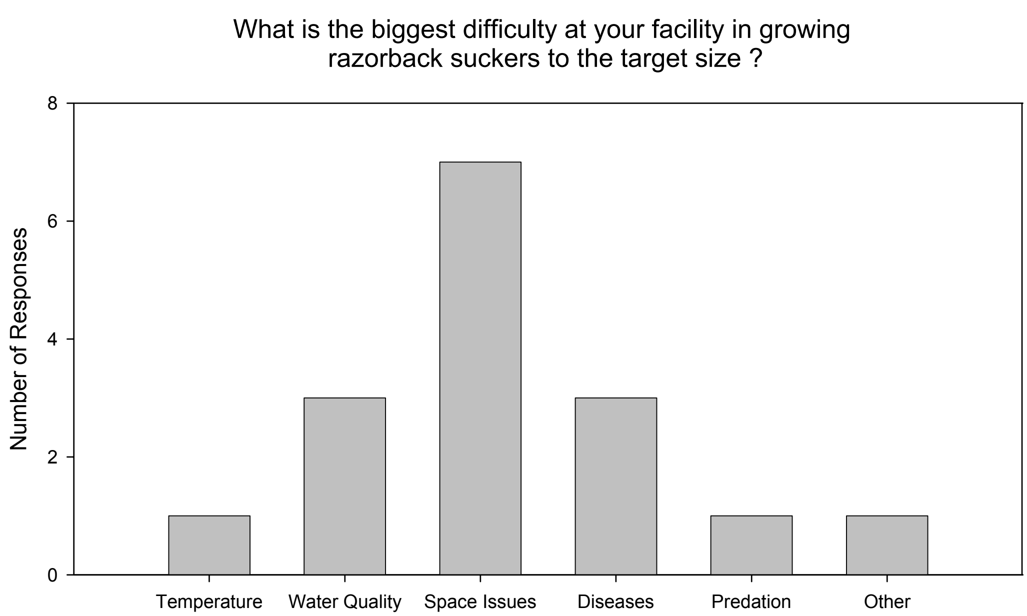
4. Would the pond be lined or unlined?
5. Would you grade or sort fish and how often?

Appendix 3. Tabulated Survey Results

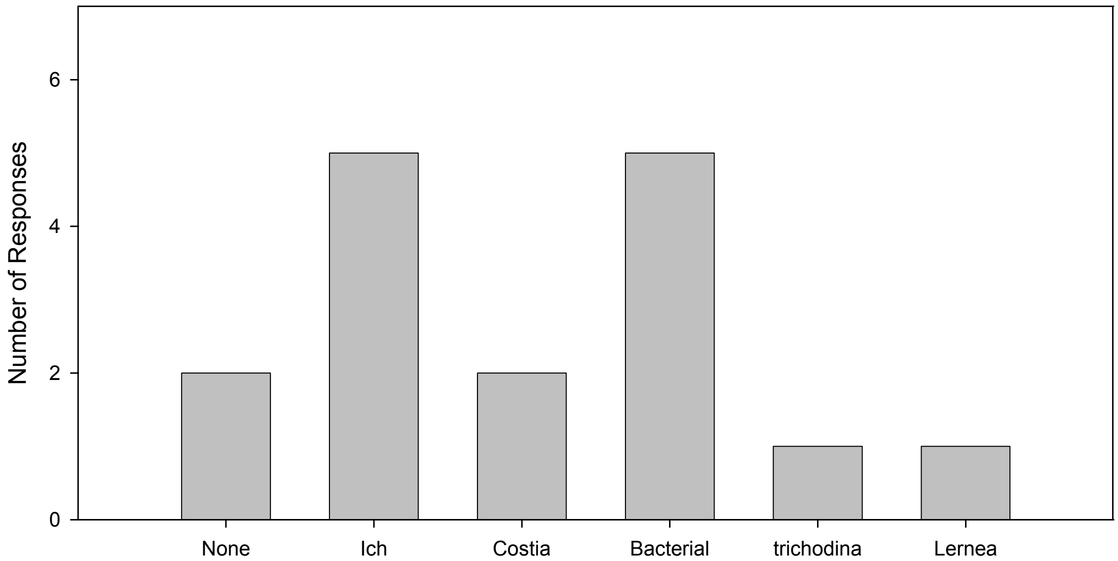
Survey Participants

Name	Facility	Telephone number	Agency
Frank Agyagos	Bubbling Ponds	928-634-4466	Arizona Game & Fish
Dave Billingsly	Bubbling Ponds	928-634-4466	Arizona Game & Fish
Dave Hampton	Dexter	505-734-5910	U.S. Fish & Wildlife Service
Manuel Ulibarri	Dexter	505-734-5910	U.S. Fish & Wildlife Service
Thad Bingham	Grand Junction	970-245-9319	U.S. Fish & Wildlife Service
Brian Scheer	Grand Junction	970-245-9319	U.S. Fish & Wildlife Service
Mike Montagne	Ouray	435-789-0351	U.S. Fish & Wildlife Service
Sam Pollock	Ouray	435-789-0351	U.S. Fish & Wildlife Service
John Scott	Willow Beach	928-767-3456	U.S. Fish & Wildlife Service
Geno Sprofera	Willow Beach	928-767-3456	U.S. Fish & Wildlife Service
Robert Krapfel	Achii Hanyo	928-853-1673	U.S. Fish & Wildlife Service
Deborah Herndon	Lake Mead	702-486-6740	Nevada Dept. of Wildlife
Quent Bradwisch	Wahweep	435-675-3714	Utah Division of wildlife Resources
Annette Morgan	Hualapai ponds	928-769-2255	Hualapai Division of Natural Resources
Joe Marrinan	Mumma	719-587-3392	Colorado Division of Wildlife
Grant Webber	Uvalde	830-278-2419	U.S. Fish & Wildlife Service

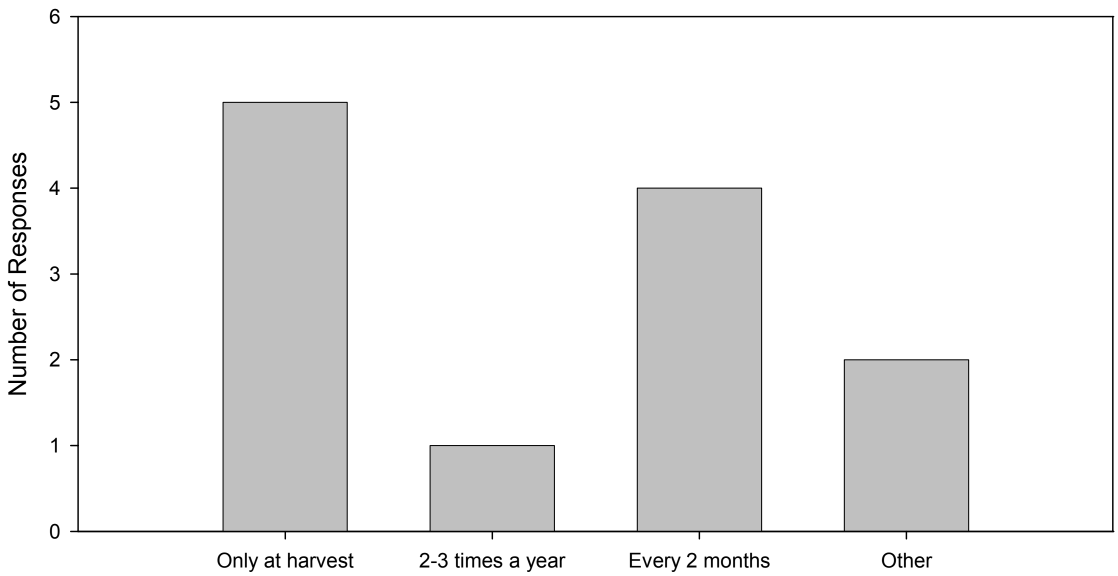
Questions about existing facilities and practices



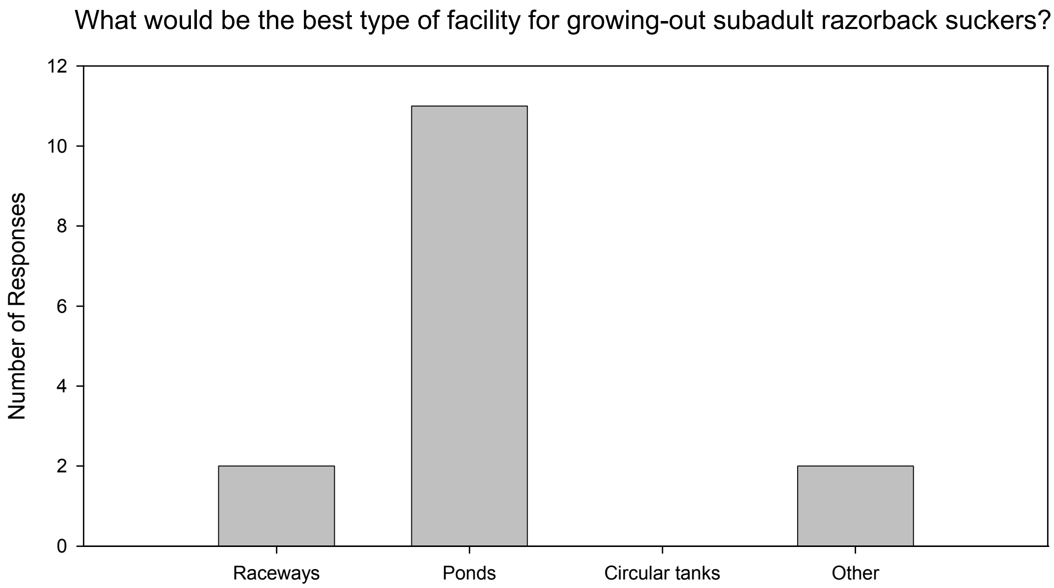
Which diseases are the most problematic at your facility?



How often do you currently sort/grade fish?



Hypothetical/Opinion Questions



* Other = combination of ponds initially and then grow-out in raceways