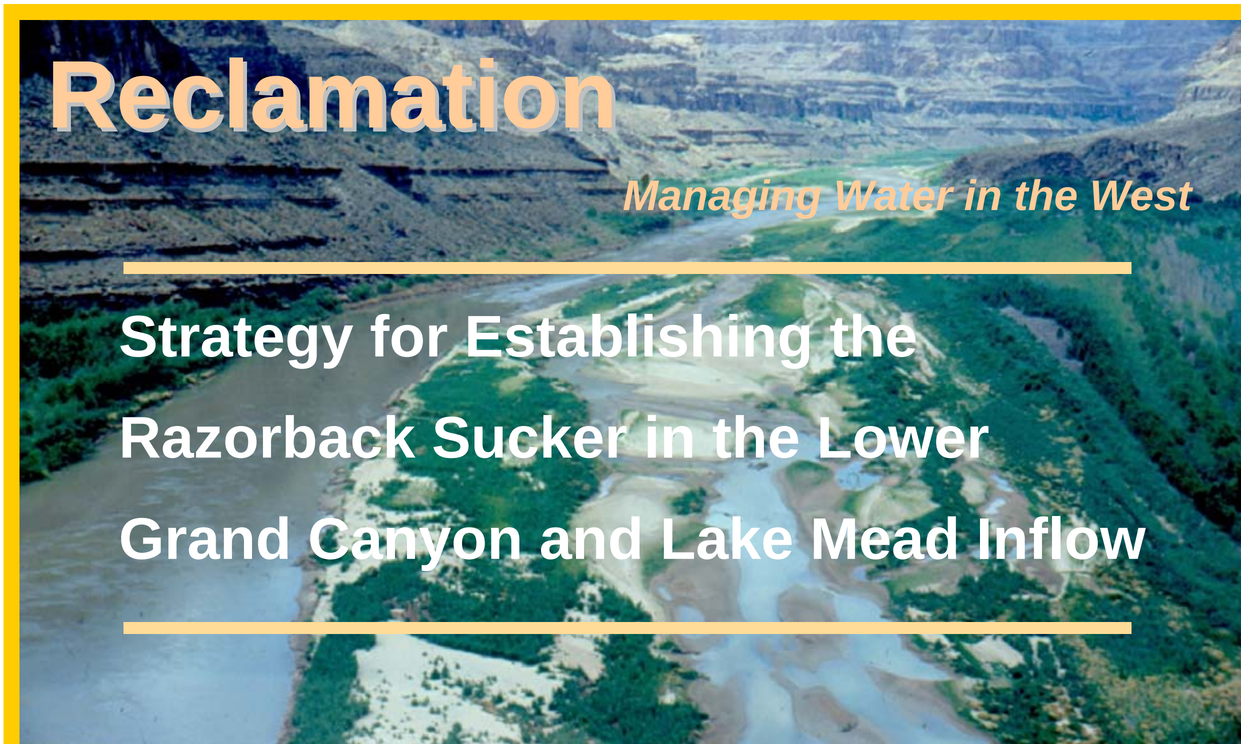
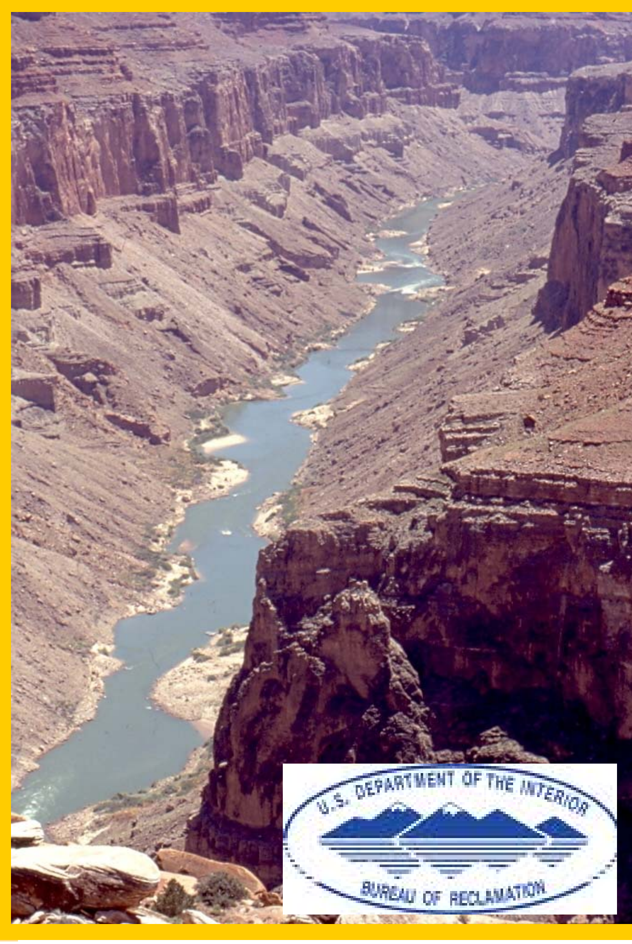


Reclamation

Managing Water in the West

Strategy for Establishing the Razorback Sucker in the Lower Grand Canyon and Lake Mead Inflow



SWCA ENVIRONMENTAL CONSULTANTS

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Cover Photos:

Top center: aerial view of lower Grand Canyon (R. Valdez, June 24, 1992); *top left:* aerial view of Dexter National Fish Hatchery and Technology Center (U.S. Fish and Wildlife Service); *bottom left:* adult razorback sucker captured in the Upper Colorado River near Grand Junction (R. Valdez, June 1980); *bottom right:* view of the Colorado River through Grand Canyon from Nankoweap Canyon, RM 52 (B. Masslich, 1990).

Disclaimer:

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Report Number 3

STRATEGY FOR ESTABLISHING THE RAZORBACK SUCKER IN THE LOWER GRAND CANYON AND LAKE MEAD INFLOW

Final Report

REPORT TO U.S. BUREAU OF RECLAMATION
UPPER COLORADO REGION
SALT LAKE CITY, UTAH

REPORT BY SWCA ENVIRONMENTAL CONSULTANTS
FLAGSTAFF, ARIZONA

Richard A. Valdez, Dorothy A. House,
Mary Anne McLeod, and Steven W. Carothers

OCTOBER 1, 2012

PREFACE

The U.S. Bureau of Reclamation (Reclamation) has undertaken an investigation to examine the potential of habitat for the federally endangered razorback sucker (*Xyrauchen texanus*) in the lower Grand Canyon. Reclamation, in collaboration with the U.S. Fish and Wildlife Service (USFWS), may institute an augmentation program for the species in that area, if appropriate. This investigation addresses part of a conservation measure of the Final Environmental Impact Statement for the Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead. The measure is contained in Concurrences (Appendix A) of the 2007 Biological Opinion for that action which states that: *"Reclamation will, as a conservation measure, undertake an effort to examine the potential of habitat in the lower Grand Canyon for the species* [razorback sucker]*, and institute an augmentation program in collaboration with FWS, if appropriate."*

Reclamation is coordinating this investigation with the U.S. Fish and Wildlife Service, Glen Canyon Dam Adaptive Management Program, Lower Colorado River Multi-Species Conservation Program, National Park Service, Grand Canyon Monitoring and Research Center, Nevada Department of Wildlife, Arizona Game and Fish Department, and the Hualapai Tribe. SWCA, Environmental Consultants was retained by Reclamation to assist with the assimilation of information for this investigation and to recommend an augmentation strategy for the razorback sucker. SWCA and Reclamation established three tasks: (1) assimilate, review, and summarize the habitat information for the species, (2) convene a Science Panel of species experts for recommended actions, and (3) develop an augmentation strategy.

This report is the third of three reports produced as part of this investigation that include:

1. *Review and Summary of Razorback Sucker Habitat in the Colorado River System*: This report summarizes habitat used by the razorback sucker throughout its range in the Colorado River System, including conditions for spawning and egg incubation; larval drift corridors and distances; nurseries used by young; juvenile rearing areas; food requirements; movement; and subadult and adult habitat. The information contained in this report was used to better gauge the suitability of conditions for the species in the lower Grand Canyon and Colorado River inflow to Lake Mead.

2. *The Potential of Habitat for the Razorback Sucker in the Lower Grand Canyon and Colorado River Inflow to Lake Mead: A Science Panel Report*: This report contains the views, opinions, and recommendations of a panel of species experts on the suitability of the lower Grand Canyon and Colorado River inflow for the razorback sucker. It was developed from a reconnaissance field trip and meetings of the Panel in September, 2010.

3. *Strategy for Establishing the Razorback Sucker in the Lower Grand Canyon and Lake Mead Inflow*: This report describes a strategy for establishment of the razorback sucker in the lower Grand Canyon, either naturally through expansion of the Lake Mead population or possibly through augmentation.

ACKNOWLEDGMENTS

The U.S. Bureau of Reclamation and SWCA Environmental Consultants appreciate the efforts of many individuals that provided support and input into this investigation and the development of the three reports (see names and affiliations below). Mark McKinstry, Reclamation's Contract Officer Technical Representative, provided the impetus, support, and guidance for this project. We thank the members of the Science Panel (highlighted below) for their critical review, evaluation, and input necessary to the development of a scientifically defensible approach for evaluating the potential for introducing razorback suckers into the lower Grand Canyon.

We thank the National Park Service for their collaboration and support of this project, especially Brian Healy, Emily Omana Smith, Nate Alvord, and Dave Loeffler of Grand Canyon National Park who provided logistical support and rafts for the reconnaissance field trip of September 16-19, 2010, through the lower Grand Canyon. We thank Greg Squires of Lake Mead National Recreation Area for providing a boat to transport the Science Panel in the Lake Mead inflow.

We thank the participants of the reconnaissance field trip for their valuable time and insight and the agencies for supporting members of their staffs to participate in this process. The Bar 10 Ranch provided aerial and ground transportation from Flagstaff, Arizona to Whitmore Wash.

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EXECUTIVE SUMMARY

The U.S. Bureau of Reclamation (Reclamation), in collaboration with the U.S. Fish and Wildlife Service (USFWS), is investigating the potential for establishment of the endangered razorback sucker (*Xyrauchen texanus*) in the lower Grand Canyon. This report describes a strategy for establishing the species through three phases: Phase I: Determine the presence of and use by razorback suckers in the lower Grand Canyon; Phase II: Assess and evaluate the viability of the Lake Mead razorback sucker population and its linkage to the lower Grand Canyon; and Phase III: Determine the appropriateness of an augmentation program for the razorback sucker in the lower Grand Canyon. Phase I consists for four tasks including: (1) continued use of telemetry, (2) reconnaissance of the large-bodied fish community, (3) characterization of the small-bodied fish community, and (4) a description of patterns of larval sucker occurrence and habitat use. Phase II is a recommended Population Viability Analysis (PVA) that can be used to evaluate the need and appropriateness of an augmentation program for the razorback sucker in the lower Grand Canyon by adding fish of different sizes and ages to the population with various survival rates to assess the effect on the overall adult population and future reproductive and recruitment potential. Phase III is a decision process in which Reclamation and the USFWS may render the decision to institute an augmentation program for the razorback sucker in the lower Grand Canyon, if appropriate.

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1.0 INTRODUCTION

1.1 Background

This report recommends a strategy for establishing the federally endangered razorback sucker (*Xyrauchen texanus*) in the Colorado River through the lower Grand Canyon and Lake Mead inflow (Figure 1). It consists of three phases that determine the extent of use of the area by the species; evaluate the viability of the population in the region; and helps to determine the need for instituting an augmentation program for the razorback suckers in the area.

This strategy was developed from information gleaned from a review of habitat used by the species in other regions of the Colorado River System (Valdez et al. 2012a) and from the input of a Science Panel (Valdez et al. 2012b). Since that information was assimilated, sonic-tagged razorback suckers from Lake Mead were detected in spring and early summer of 2012 upstream from the Lake Mead inflow and in the lower Grand Canyon up to and around Quartermaster Canyon, about 20 mi upstream from Pearce Ferry (Kegerries and Albrecht 2012). Rising lake levels in 2012 inundated the Pearce Ferry rapid and evidently facilitated upstream fish movement, although the lower Grand Canyon had not been previously monitored with telemetry and fish using the area could have gone undetected.

The information contained in this report may be used by the U.S. Bureau of Reclamation (Reclamation) in collaboration with the U.S. Fish and Wildlife Service (USFWS) to institute an augmentation program for the razorback sucker, as deemed necessary and appropriate (see Reclamation 2007; USFWS 2007). This report and the two companion reports cited above are designed to assist Reclamation and the USFWS in determining if augmentation of the razorback sucker is appropriate or feasible for establishing the species in the lower Grand Canyon.

1.2 Species Status

The razorback sucker was recognized as an imperiled species in the early 1900s (Minckley 1983), and initial efforts to conserve the species were conducted locally by State and Federal agencies together with volunteer efforts (Minckley et al. 1991). The razorback sucker was listed as "endangered" under the Endangered Species Act of 1973, as amended (ESA; 16 U.S.C. 1531 *et. seq.*) on October 23, 1991 (56 FR 54957) with critical habitat designated on April 20, 1994 (59 FR 13374). A recovery plan was approved on December 23, 1998 (USFWS 1998) and Recovery Goals were approved on August 1, 2002 (USFWS 2002).

Critical habitat was designated in 1994 as 2,776 km (1,724 mi; Figure 1) of the Colorado River and its tributaries in the upper and lower basins. This designation laid the foundation for potential population restoration sites, and the Razorback Sucker Recovery Plan (USFWS 1998) called for protecting and restoring habitat, augmenting or establishing populations with cultured fish, and maintaining existing genetic diversity. These concepts were carried forward into the 2002 Recovery Goals (USFWS 2002) that require four genetically and demographically viable, self-sustaining populations (established or augmented with hatchery stocks), including two each in the upper and lower Colorado River basins.

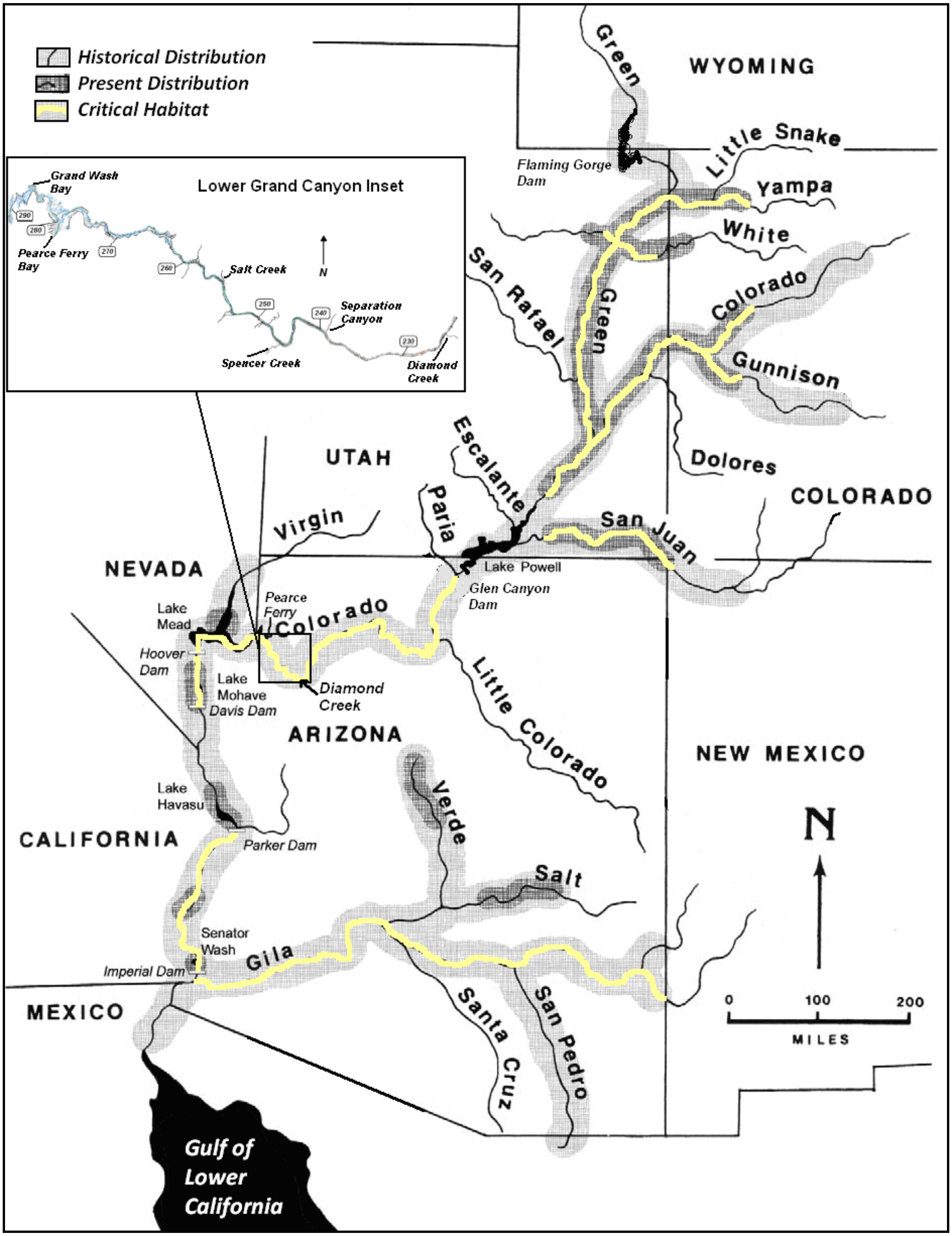

Figure 1. Historical and present distribution of the razorback sucker with designated critical habitat in the Colorado River System (adopted from Maddux et al. 1993 and Schooley and Marsh 2007). A detailed inset map of the Lower Grand Canyon from Diamond Creek to Pearce Ferry is provided.

2.0 RECOMMENDED STRATEGY

The following is a recommended strategy for establishing the razorback sucker in the lower Grand Canyon and Lake Mead inflow. The strategy consists of three phases:

1. Phase I: Determine the presence of and use by razorback suckers in the lower Grand Canyon;
2. Phase II: Assess and evaluate the viability of the Lake Mead razorback sucker population and its linkage to the lower Grand Canyon; and
3. Phase III: Determine the appropriateness of an augmentation program for the razorback sucker in the lower Grand Canyon.

2.1 Phase I: Determine Presence and Use of Lower Grand Canyon

The presence of razorback suckers in the lower Grand Canyon was confirmed when five unique fish were detected at two Submersible Ultrasonic Receivers (SURs) upstream of Pearce Ferry in spring and summer of 2012. These SURs were placed and monitored by Bio/West starting in spring 2012 (Kegerries and Albrecht 2012). The SURs were placed at the Pearce Ferry boat ramp (RM 280), Bat Cave (RM 267) and Quartermaster Canyon (RM 260). The fish detected at these SURs had been sonic-tagged in Lake Mead in July and August of 2011 (a detailed Bio/West report was not available at the time of this document). Three of these fish were first detected between Pearce Ferry and the Grand Wash inflow starting in February 2012. These fish remained upstream of Pearce Ferry until May or June 2012 and then moved back downstream into the Lake Mead inflow and lake proper.

The numbers of razorback suckers in the lower Grand Canyon upstream of Pearce Ferry is unknown. The telemetered fish detected in early 2012 were fish from Lake Mead that may have been exploring new available habitats following a rise in lake elevation. Possibly movement into the lower Grand Canyon is part of a regular life history pattern by some Lake Mead fish that have gone undetected for lack of telemetry monitoring in the area. It is also possible that some razorback suckers are residents of the lower Grand Canyon and use the lake inflow as part of their life history. The Lake Mead razorback sucker population is the largest known reproducing population, and understanding the linkage in use of Lake Mead and the lower Grand Canyon may be vital for conserving and possibly expanding this population.

As the first phase of this strategy, it is important to understand the extent of use by the razorback sucker of the lower Grand Canyon and to estimate the numbers of fish in the area. The following tasks are recommended:

1. **Continued Use of Telemetry**.

Sonic tags are currently being used effectively to monitor movements of razorback suckers in Lake Mead (e.g., Albrecht et al. 2010). Sonic tags may not be as effective as radio tags in the riverine environment of the lower Grand Canyon, and it may be necessary to use a combination sonic and radio telemetry for monitoring fish moving between the lake and the river. The most appropriate tags and telemetry systems should be determine by scientists working in the region and most knowledgeable with this technology. Telemetry should continue to be used as a tool to:

a. **Detect fish moving upstream from the Lake Mead population**: Given that there is an ongoing effort to sonic-tag razorback suckers in Lake Mead, active and passive monitoring should be done in the lower Grand Canyon as far upstream as Lava Falls rapid to determine the extent of movement by fish from the lake into the river. Passive monitoring should include the establishment of multiple strategically-located SURs for detecting year-around movement. Active monitoring should also be done by crews in the area to assess habitat use, daily movements, and fish associations.

b. **Determine if razorback suckers in the lower Grand Canyon are transient or resident**: The fish detected above Pearce Ferry in 2011-2012 remained in the lower Grand Canyon for about 5 months (February through June). It is important to determine if the lower Grand Canyon is being used seasonally by fish from Lake Mead possibly for feeding and/or spawning; or if there are fish in the lower Grand Canyon as permanent residents. It may be appropriate to translocate telemetered fish from captivity (e.g., Floyd-Lamb) into the lower Grand Canyon to supplement the numbers of known fish in the area and to determine if fish will remain in the lower Grand Canyon. If appropriate, 10–15 fish should be translocated and released as far upstream as Lava Falls rapid, or in pools adjacent to potential spawning bars at Diamond Creek, Spencer Canyon, and Salt Creek. The fish should be tracked immediately after release to determine if they will remain in the area or move downstream to the lake. These fish can also be used to locate other razorback suckers associated in preferred habitats. Releasing razorback suckers upstream of Lava Falls rapid is not recommended because of the lack of a full complement of suitable habitat for the species and the great distance for drifting larvae to known nursery habitat in the Lake Mead inflow. Use of wild telemetered fish from Lake Mead is not advised, although “wild” fish caught in the lower Grand Canyon should be considered for telemetry.

c. **Locate additional razorback suckers**: Telemetry should be used in tandem with sampling for large-bodied fish. Telemetered fish can be used as “Judas fish” to reveal the possible presence of other razorback suckers aggregated in the same area.

d. **Document habitat use in the lower Grand Canyon**: Habitat used by various life stages of the razorback sucker in the lower Grand Canyon should be documented. If fish from Lake Mead are using this area for feeding and/or spawning, it will be important to determine if these areas need protection or may be enhanced. Understanding if spawning is occurring in the lower Grand Canyon and the habitats used for spawning and larval rearing is also important in providing a better understanding of the linkage between Lake Mead and the Colorado River inflow in the conservation and recovery of the species.

2. Reconnaissance Large-Bodied Fish Community.

The primary purpose of this task should be to reconnaissance the fish species in the area, determine relative abundances, determine the proportion of native suckers in the area (razorback, flannelmouth, and bluehead), and estimate the numbers of razorback suckers in the lower Grand Canyon. Selective sampling should be done for large-bodied fish from Lava Falls rapid to Pearce Ferry (RM 169-280). The most effective gear types are trammel nets and large hoop nets set continuously and for several days in select habitats. These should be placed in the most likely habitats and used in tandem with and in proximity of telemetered fish. The razorback sucker is a social species and there is a good chance that telemetered fish may be accompanied by other un-tagged fish. Electrofishing is not considered very effective for capturing razorback suckers in a turbid riverine environment, and extensive use of this gear in the lower Grand Canyon is not advised.

All fish captured should be recorded to species, and lengths and weights of samples should be recorded. Native fish should be permanently marked consistent with ongoing Lake Mead and Grand Canyon protocols for fish monitoring. This sampling should be coordinated with annual sampling by the Grand Canyon Monitoring and Research Center (GCMRC) below Diamond Creek and with the Lake Mead Razorback Sucker Work Group below Pearce Ferry. Where possible, the numbers of native suckers should be estimated with mark-recapture methods, or at least catch-per-effort should be recorded as numbers of fish per 10 hours of trammel nets or hoop nets set. This reconnaissance should also establish the proportional age categories for each native sucker to better understand how the lower Grand Canyon is used by these species (e.g., for spawning, nursing, rearing, feeding).

3. Characterize Small-Bodied Fish Community.

The primary purpose of this task is to determine if young native suckers, particularly the razorback sucker, are rearing in the lower Grand Canyon. Intensive seining is recommended in backwaters and other shallow, sheltered habitats that may support juvenile suckers. The numbers of flannelmouth and bluehead suckers in the Grand Canyon has increased since about 2004, and possibly razorback suckers are aggregated with these related species in key habitats (see Valdez et al. 2012a). All fish captured should be recorded to species and lengths and weights of samples should be recorded. Native fish of suitable size should be permanently marked consistent with ongoing Lake Mead and Grand Canyon protocols for fish monitoring. The relative abundance of native suckers should be estimated with catch-per-effort as numbers of fish per 100 m^2 seined.

4. Describe Patterns of Larval Sucker Occurrence and Habitat Use.

Larval and post-larval fish sampling should be conducted from Lava Falls rapid to Pearce Ferry to identify fish species spawning in the area, possible spawning locations, timing of spawning, and numbers of young produced in the area as well as entering and leaving the lower Grand Canyon. Larval and post-larval fish should initially be collected once a month for about 7 months (February–July) from different habitats (shorelines, backwaters, etc.) to document species presence and habitat use. Once the timing of spawning by razorback suckers is established for the lower Grand Canyon, the window of sampling should be narrowed accordingly. Larval fish sampling in the lower Grand Canyon should be coordinated with larval fish sampling in the Lake Mead inflow.

2.2 Phase II: Assess and Evaluate Population Viability

Ongoing work with the razorback sucker in Lake Mead demonstrates the connectivity between groups of fish in Lake Mead and a possible linkage to the Colorado River in lower Grand Canyon (Albrecht et al. 2010; Kegerries and Albrecht 2012). The possible connection between Lake Mead and the lower Grand Canyon as part of the life history of fish in the region is significant with respect to conservation and recovery of the razorback sucker. The Colorado River is the largest inflow to Lake Mead and understanding its role and importance to the species—given the discovery of telemetered fish in lower Grand Canyon in 2012—now becomes an important aspect of future investigations for the species in this area of the Colorado River Basin.

The numbers of razorback suckers in apparent metapopulations in Lake Mead (i.e., Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River inflow area) have been estimated and some of the vital demographic parameters (e.g., adult survival, recruitment to adults) have been determined. However, specific variables that most influence population size are not well understood (e.g., age-specific survival, lake elevation as it affects habitat, etc.). Confirmed spawning at the Colorado River inflow in 2010, 2011, and 2012 and collection of larvae in the inflow indicate that a fourth metapopulation is present with possible linkages to the Colorado River in the lower Grand Canyon. There has been a considerable amount of information collected on the vital demographic parameters for each of the four apparent metapopulations and the extent of connectivity between and among them has been documented with telemetry. However, the importance of each of these groups of fish to the long-term viability of the greater Lake Mead population cannot be readily evaluated without the aid of a population model that can assemble the available information into a comprehensive evaluation of long-term population viability.

Population viability analysis (PVA) has become a common tool for assessing the viability and risk of extinction for many endangered and threatened species (e.g., Beissinger and McCullough 2002). Age-structured stock-recruitment models are often used as the centerpiece of these PVAs to assess the impact of various management scenarios on species viability, including population augmentation. A PVA has not been developed for the razorback sucker and there are no recent models that have been developed for similar sucker species, although a population simulation model was developed for the cui-ui (*Chasmistes cujus*) (Emlen et al. 1993). Nevertheless, the expertise and technology for developing a PVA is readily available, including commercial software (e.g., RAMAS Metapop; Applied Biomathematics, Setauket, NY).

Population viability analysis is a meaningful and useful tool for better understanding the dynamics of the Lake Mead razorback sucker population and the relationship of this population to the lower Grand Canyon, as well as the efficacy of an augmentation program for population enhancement and species recovery. An age-structured stock-recruitment model will require vital demographic parameters, including age composition, age-specific survival, recruitment, maternity, estimated species abundance, and linkages among metapopulations. These vital demographic parameters are important for understanding populations and should be quantified as part of ongoing investigations of the razorback sucker.

2.3 Phase III: Determine Appropriateness of Augmentation Program

An augmentation program for the razorback sucker in the lower Grand Canyon cannot be developed at this time because the status of the species in the area is unknown and the prospect for expanding the Lake Mead population is uncertain (see Valdez et al. 2012b). Phase I of this strategy is designed to determine the extent of use by the species of the lower Grand Canyon and the approximate numbers of fish involved. Phase II is a recommended population viability analysis that should provide the tool for better understanding the linkages among Lake Mead metapopulations and the role and appropriateness of an augmentation program for the lower Grand Canyon. Phase III should consist of an assimilation of information and an ongoing dialogue among the collaborators to ensure a timely decision to determine if an augmentation program will be necessary and appropriate.

As the information is brought together that assesses the viability of the razorback sucker population in this region of the Colorado River, Reclamation and the USFWS should continue to coordinate activities and the decision to institute an augmentation program. This decision should be made in collaboration with the Glen Canyon Dam Adaptive Management Program, Lower Colorado River Multi-Species Conservation Program, National Park Service, Grand Canyon Monitoring and Research Center, Nevada Department of Wildlife, Arizona Game and Fish Department, and the Hualapai Tribe.

Appendix A of this report has been assembled to bring together information on the culture of the razorback sucker and the history of releasing of these fish to augment wild populations or reestablish the species in historic habitat. This appendix and the Science Panel Report (see Valdez et al. 2012b) are provided as an insight into the issues that may surround development of an augmentation program and the release of fish into the lower Grand Canyon.

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APPENDIX A: CULTURE AND AUGMENTATION OF THE RAZORBACK SUCKER

A-1.0 Introduction

This appendix has been assembled to bring together information on the culture of the razorback sucker and the release of these fish to augment wild populations or reestablish the species in historic habitat. The genesis of augmentation is described, as well as an overview of the history of hatchery culture for the species. This appendix identifies the propagation and grow-out facilities, and the approaches and methods used for propagation and augmentation. Also, a history of the numbers of fish released and their survival rates are provided as insight on those methods that have shown to be the most successful.

A-1.1 Genesis of Augmentation

Listing of the species in 1991 resulted in more widespread and coordinated efforts toward conservation, including the stocking of fish to establish new populations and augment existing ones. A status review of the species (Bestgen 1990) revealed extensive range reduction, losses of populations, and declining numbers of individuals throughout its remaining distribution, with the largest remaining numbers in Lake Mohave and the upper Green River. This status review recommended the development of a hatchery broodstock and refugia population, but cautioned that simply stocking large numbers of razorback suckers into a variety of existing habitats would not recover the species; rather, controlled experiments would be needed to better understand the limiting factors for natural recruitment and necessary habitat.

Listing the razorback sucker also raised the level of species protection and conservation with the establishment of five major conservation programs in the Colorado River System (USFWS 2002), including: (1) Upper Colorado River Endangered Fish Recovery Program (UCRRP), (2) San Juan River Basin Recovery Implementation Program (SJRIP), (3) Glen Canyon Dam Adaptive Management Program (GCDAMP), (4) Native Fish Work Group (NFWG), and (5) Lower Colorado River Multi-Species Conservation Program (MSCP). Each of these programs conducts and supports activities that include augmentation of existing or new populations with fish raised in captivity.

As part of the effort to restore populations of razorback suckers in the wild, the USFWS has included stocking fish as part of the requirement of Section 7 compliance under the ESA. Under the terms of a Biological Opinion for Lower Colorado River operations and maintenance (USFWS 1997), Reclamation was required, by the year 2000, to annually stock 50,000 adult razorback suckers in Lake Mohave and 25,000 in Lake Havasu. These activities were conducted and coordinated by the NFWG and MSCP. An evaluation of long-term survival of these stocked fish has revealed new strategies for improving successes of these stocks (see section 2.4).

A-1.2 Overview of Augmentation

Razorback suckers have been raised in captivity since the early 1970s (Toney 1974; Inslee 1981) and used to augment declining populations in many parts of the Colorado River System (e.g., Creef et al. 1992; Creef and Clarkson 1993; Hendrickson 1993; Carmichael et al. 1996; Foster and Mueller 1999; Modde and Haines 2005; Mueller and Burke 2005). Propagation techniques for the species have been developed and refined, and culture facilities have the capability and capacity to raise large numbers of fish in captivity. Initially, millions of small razorback suckers were stocked into rivers and reservoirs of the Colorado River System, but low survival rates have led to a refinement of propagation, grow-out, and release methods. Recently, there has been a transition from stocking large numbers of small fish toward stocking fewer larger fish that have a higher rate of survival (e.g., Mueller 1995; Modde et al. 1995; Ryden 1997; Burdick 2003; Schooley and Marsh 2007; Zelasko et al. 2009, 2010).

Ongoing concerns over maintaining genetic viability, fitness of fish to the receiving waters, imprinting to local habitats, and losses to predation and competition from nonnative fishes have also lead to a continued and ongoing evaluation and refinement of rearing and release methods. These propagation, grow-out, and release methods continue to be refined based on ongoing investigations and new approaches are being tested in the hatcheries and in the field. The following section describes the development of these methods and the refinements.

A-2.0 Propagation and Grow-Out Facilities

Nine major facilities or programs currently propagate, grow out, and release the razorback sucker (Figure 1). Fish raised in these facilities are used to reestablish populations in historical range, augment existing populations, and for research. Seven of these facilities are located within the Colorado River System and two (Dexter NFHTC and Uvalde NFH) are located outside of the drainage.

The basic information associated with each facility is presented in Table A-1, including the approximate numbers of broodstock fish on-site. Some of these facilities have been in operation for a number of years and have transferred fish to and from various locations. Altogether, about 15 million razorback suckers have been stocked from these facilities into the wild since about 1980.

The specific numbers of fish produced and stocked from each facility are not provided, but can be procured from records for each site. Other facilities have in the past propagated the razorback sucker and a number of research institutions have held or currently hold the species; e.g., Lake Havasu Fishery Improvement Project, Boulder City Golf Course Native Fish Rearing Project, Hualapai Native Fish Rearing Facility. These facilities are not described herein, other than to identify propagation or release methods that may apply to the lower Grand Canyon.

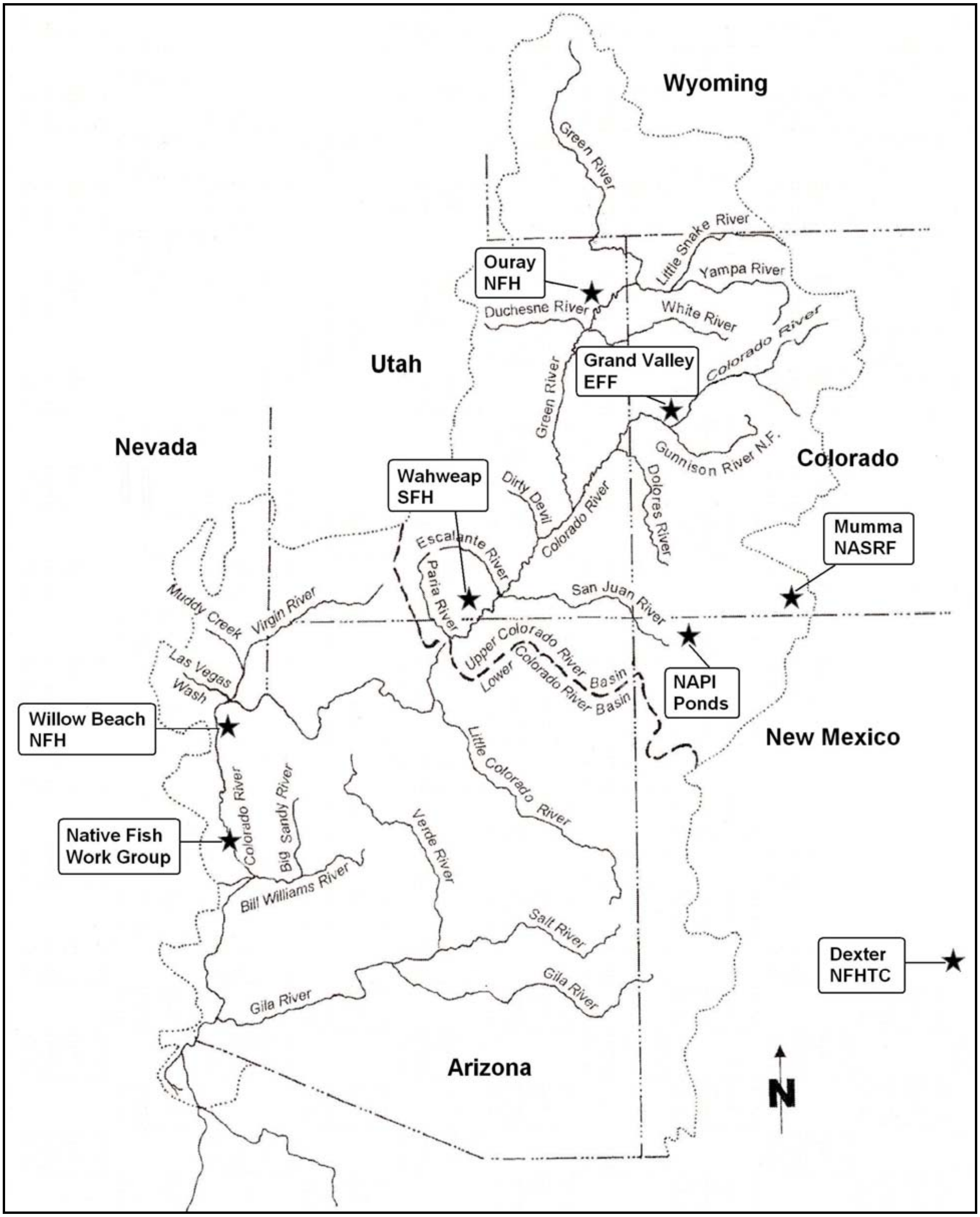

Figure A-1. Locations of eight major propagation facilities for the razorback sucker relative to the Colorado River System. The ninth location at the Uvalde National Fish Hatchery near Uvalde, Texas is not shown.

Table A-1. Existing major propagation facilities or programs for the razorback sucker (RBS), their principal role in species conservation, the numbers of broodstock fish on-site, and approximate miles of highway distance to Diamond Creek, the principal road access point to the lower Grand Canyon.

Facility	Agency	Year Started	Primary Role for RBS	Recent RBS Broodstock	Highway Distance to Diamond Creek
Willow Beach National Fish Hatchery	U.S. Fish and Wildlife Service	1974	First native fish hatchery for Southwest U.S. Spawners taken from Lake Mohave, spawned, and returned.	Variable numbers of wild fish from Lake Mohave	Willow Beach, AZ (~75 mi)
Dexter NFHTC	U.S. Fish and Wildlife Service	1981	Primary native fish hatchery for Southwest U.S. endangered fish species. Produce young RBS from broodstock for stocking throughout System.	~300 adults from primarily Lake Mohave	Dexter, NM (~600 mi)
Ouray National Fish Hatchery	U.S. Fish and Wildlife Service	1986	Established to preserve unique genetics of wild Green River fish. Fish produced are stocked in Green River.	~660 adults from Green, Colorado, San Juan rivers	Vernal, UT (~450 mi)
Grand Valley Endangered Fish Facility	U.S. Fish and Wildlife Service	1992	Production meets stocking goals for Gunnison, Upper Colorado, and San Juan rivers. Also provide fish for NAPI grow-out ponds.	~300 adults; mix from Upper Colorado, Green. Sam Juan rivers, Etter Pond, Willow BeachIMohave	Grand Junction, CO (~450 mi)
Wahweap State Fish Hatchery	Utah Division of Wildlife Resources	1993	Maintains back-up broodstock for Green River fish for Ouray NFH; fish not spawned on site.	~925 adults; back-up broodstock for Green River fish from Ouray NFH	Big Water, UT (~150 mi)
J.W. Mumma Native Aquatic Species Restoration Facility	Colorado Department of Wildlife	2000	Primarily a grow-out facility for fish received from other sources; fish not spawned on site.	No broodstock; primarily a grow-out facility	Alamosa, CO (~400 mi)
Uvalde National Fish Hatchery	U.S. Fish and Wildlife Service	2006	Functions as a grow-out facility for larvae spawned at Dexter NFHTC	No broodstock; grow-out facility only with target of 11,400, 300 mm RBS for stocking San Juan River	Uvalde, TX (~850 mi)

Facility	Agency	Year Started	Primary Role for RBS	Recent RBS Broodstock	Highway Distance to Diamond Creek
Native Fish Work Group	U.S. Bureau of Reclamation	1990	Established to prevent disappearance of RBS from Lake Mohave. Collect wild larvae from reservoir for grow-out in sanctuary coves and ponds.	Annually collect wild larvae from Lake Mohave	Lake Mohave (~125 mi)
Navajo Agricultural Products Industry (NAPI) Ponds	Navajo Nation			No broodstock; primarily grow-out ponds with target of 6,000, 300 mm RBS for stocking San Juan River	Farmington, NM (~150 mi)

A-2.1 Willow Beach NFH

The Willow Beach National Fish Hatchery (NFH) was the first facility to hold the Colorado River endangered species. It was built in 1962 about 11 mi downriver from Hoover Dam. The facility uses cold water from the dam and raises primarily rainbow trout (*Oncorhynchus mykiss*) for stocking in nearby lakes Mohave and Mead as mitigation for the construction of the dams of the Lower Colorado River. Although trout are still stocked from the hatchery to provide recreational fishing opportunities, imperiled fishes like the razorback sucker and bonytail (*Gila elegans*) are also propagated or held on site for research and for release to the wild.

Willow Beach NFH was the first hatchery to receive razorback suckers from the wild in the early 1970s (Toney 1974; Inslee 1981). On March 27, 1974, a joint Federal-State Recovery Team collected 40 adults near Cottonwood Cove, Lake Mohave and transported them live to the Willow Beach NFH (Valdez 1985). Some eggs were stripped and collected on site and moved with the fish to Willow Beach. On May 7, 1974, 32 of these fish were transferred to the Arizona State Fish Hatchery at Page Springs. The progeny of these fish were used for research and for release back to the wild. Much of the responsibility for raising Colorado River endangered fish was transferred from the Willow Beach NFH to the Dexter NFHTC in the 1980s.

Willow Beach NFH currently receives ripe adult razorback suckers from Lake Mohave, spawns the fish on site, and transfers the progeny to grow-out ponds in the lower basin. The facility houses a variable number of wild razorback suckers from Lake Mohave, depending on time of year, but does not house a broodstock.

A-2.2 Dexter NFHTC

The Dexter National Fish Hatchery and Technology Center (NFHTC) is located in the Pecos River Basin in southeastern New Mexico. The NFHTC houses a Fish Culture Facility, Molecular Ecology Lab, and Fish Health Unit. In 2011, the center held over 1 million individuals of 15 different threatened and endangered fish species. The Dexter NFHTC works with partners to reintroduce species into their native habitats; improve the quality of fish reared through genetic research; and maintain populations in the event of catastrophic loss in the wild.

The Dexter National Fish Hatchery was established in 1932 to meet the demands for warm water sport fishing in the southwest. With passage of the ESA in 1973, there began a growing demand for propagation of threatened and endangered fishes, and the mission of the facility was transitioned from raising fish for recreational purposes to propagating, housing, and protecting imperiled fish species; the Dexter NFH became the Dexter NFHTC in 1984.

The Dexter NFH began work with the razorback sucker in January of 1981 and 1982 when 134 and 147 wild adults from Lake Mohave were transferred from Willow Beach NFH (Minckley and Brooks 1985). These fish became the basis for development of a broodstock at that facility, and some of these fish remain there today. From 1981 to 2004, the Dexter NFH and NFHTC produced more than 15 million razorback suckers (Dexter NFHTC, unpublished data, 2004, cited in Mueller 2006). Dexter NFHTC maintains a broodstock of about 300 razorback suckers and produces young suckers that are either directly stocked downstream of Davis Dam or are grown out at other facilities and stocked elsewhere.

A-2.3 Ouray NFH

The Ouray National Fish Hatchery (Randlett Unit) is located on the Ouray National Wildlife Refuge about 35 mi southwest of Vernal, Utah. The razorback sucker was first held at the facility in 1989 when wild adults were collected from the middle Green River and from the San Juan arm of Lake Powell. The Green River fish were used to develop a captive broodstock, and the San Juan arm fish were later transferred to the Grand Valley Endangered Fish Facility near Grand Junction, Colorado. From 1989 to 1991, three lots of future broodstock (one annually) were created using a mixed stock of 15 females and 13 males of Green River origin. From 1993 to 2001, 25 unique family lots were created using predominantly the Green River stock. Two of the lots created in 2001 are from F_1 parents of the San Juan and Colorado River arms of Lake Powell after the fish were transferred back from the Grand Valley Endangered Fish Facility (Bingham et al. 2010).

The Ouray NFH brood stock was established on the premise that fish surviving in the Green River possessed unique survival characteristics worth preserving (Williamson and Wydoski 1994). Altogether, Ouray NFH holds about 660 adults from the Green, Colorado, and San Juan rivers and produces fish for release into the Gunnison, Colorado, and middle and lower Green River. It currently maintains a broodstock of about 500 genetically sound Green River razorback suckers (25 lots) and continues to rear about 23,000 young to meet stocking goals for 2011. These fish are used for floodplain wetland studies and hatchery production for population augmentation. The production goal is to rear 14,895 subadults that are 300+ mm total length (TL) for release in the middle and lower Green River in Utah.

A-2.4 Grand Valley Endangered Fish Facility

The Grand Valley Endangered Fish Facility (EFF) is part of the Grand Valley Unit of the Ouray NFH (the Randlett Unit is the other). Captive rearing of endangered fish for the Upper Colorado River Basin began in the Grand Valley in 1992 with establishment of the Horsethief Rearing Ponds, where about 350 adult razorback suckers are currently held as broodstock (Bingham et al. 2010). Additional propagation facilities were established in 1996 when the 24-Road Hatchery was constructed by modifying an existing warehouse near Grand Junction, Colorado. The hatchery was expanded in the winter of 1998–1999, and now houses two separate water re-use systems. In addition to the hatchery expansion, numerous ponds have been acquired and are used to grow razorback suckers for stocking into the Colorado, Gunnison, and San Juan rivers.

Razorback suckers produced at the Grand Valley EFF are: (a) held on-site until large enough to stock (>200 mm TL); or (b) held for 1 year then stocked in grow-out ponds until large enough to stock (>200 mm TL). Most of these fish are released into the Upper Colorado and Gunnison rivers.

The construction of 22 grow-out ponds at the Horsethief Canyon Native Fish Facility is proposed to begin in 2011 with ponds becoming operational in 2012. These ponds will replace leased ponds in the Grand Valley and will improve the efficiency of raising the numbers and sizes of razorback suckers needed to meet stocking targets for the Upper Colorado River and San Juan River recovery programs.

A-2.5 Wahweap State Fish Hatchery

The Wahweap State Fish Hatchery (SFH) was established in 1993 at Big Water, Utah, near the Wahweap Marina on Lake Powell. The facility is administered by the Utah Division of Wildlife Resources and raises primarily bonytail for stocking in the Upper Colorado River Basin. The Wahweap SFH also maintains the Upper Basin's backup broodstock for razorback sucker, which is 418 fish that average 471 mm TL.

The goal of the Wahweap SFH is to operate a genetically sound propagation program for high priority endangered fish species for the Upper Colorado River Endangered Fish Recovery Program (Olsen 2010). The facility operates and maintains propagation facilities that are needed to hold, rear, or produce captive-reared endangered fishes for the upper basin in accordance with an Annual Propagation Facilities Operation Plan.

A-2.6 Mumma Native Aquatic Species Restoration Facility

The J.W. Mumma Native Aquatic Species Restoration Facility (NASRF) was built in 2000 near the city of Alamosa, Colorado. It is administered by the Colorado Parks and Wildlife, and is the primary hatchery facility for threatened and endangered aquatic species for the State of Colorado. This facility has raised bonytail and razorback sucker transferred from other facilities, and is currently raising bonytail to meet state and federal stocking requirements in the Green and Colorado rivers. Depending on existing demands and space, the Mumma NASRF could hold and raise razorback suckers (Schnoor and Marrinan 2009).

A-2.7 Uvalde National Fish Hatchery

The Uvalde National Fish Hatchery is a warmwater fish production station located in central Texas. Razorback sucker larvae are received from Dexter NFHTC, raised to ~ 300 mm TL (average size usually exceeds 325 mm TL each year), and stocked into the San Juan River (Furr and Davis 2009). In 2010, Uvalde NFH stocked 4,021 razorback suckers from the 2006 year class in the San Juan River, including 2,000 below Shiprock Bridge (mean, 455 mm TL; range, 333-560 mm TL) and 2,021 below the Animas River confluence (mean, 438 mm TL; range, 318-545 mm TL).

A-2.8 Native Fish Work Group

The Native Fish Work Group (NFWG) of the Lower Colorado River Basin began activities on Lake Mohave in 1989 as a multi-agency work group for the purpose of preventing the disappearance of the razorback sucker from the reservoir by replacing the old relic population with young adults (Mueller 1995, 2006). The NFWG is composed of biologists and resource managers from seven federal and state agencies including the Arizona Game and Fish Department, Arizona State University, Bureau of Reclamation, Biological Resources Discipline of the U.S. Geological Survey, National Park Service, Nevada Division of Wildlife, and the U.S. Fish and Wildlife Service.

The population in Lake Mohave declined by about 60%; from 59,500 in 1988 to 23,300 in 1992 (Mueller 2006). Efforts to have wild fish spawn in isolated backwaters gradually evolved to collecting wild larvae from the reservoir and raising them to a size large enough to ensure survival in the presence of a suite of predators in the reservoir. From about 1995 to 2005, more than 500,000 larvae were collected and transferred to Willow Beach NFH for initial rearing (Tom Burke, Bureau of Reclamation [BOR], personal communication, 2004; cited in Mueller 2006). Some fish were reared on-site; others were moved to other locations for further grow-out, including: Bubbling Ponds, Arizona; Niland, California; golf course ponds in Page, Arizona and Boulder City, Nevada; Parker, Arizona; and Lake Mohave backwaters (Mueller 1995).

A-2.9 Navajo Agricultural Products Industry (NAPI) Ponds

The NAPI ponds are grow-out ponds for razorback sucker that were part of the Biological Assessment and Biological Opinion of the USFWS and the Bureau of Indian Affairs that allowed the construction of Blocks 9-11 of the Navajo Indian Irrigation Project (NIIP). The Section 7 consultation on the NIIP for Blocks 1 through 8 was finalized in October 1991. Three grow-out ponds were designated to be stocked annually with 3,000-3,500 (> 200 mm TL) hatchery-reared razorback suckers produced at Dexter NFHTC using a single cohort strategy; i.e., PIT-tagged and stocked in the San Juan River at 300 mm TL after 8 months in captivity.

The San Juan River Long Range Plan (SJRIP 2009) identifies the need to assess the feasibility and implementation of razorback sucker augmentation in the San Juan River. The revised augmentation plan (Ryden 2005) and stocking plan and protocols for the NAPI ponds (Furr and Davis 2009) provides the necessary guidance for those efforts to fulfill the augmentation needs of the Long Range Plan.

A-3.0 Propagation and Grow-Out Approaches

The decline of the razorback sucker throughout the Colorado River System by the 1960s raised concern over the losses of populations and genetic diversity for the species (Minckley et al. 1991). In response to this concern, artificially propagated fish were used to augment declining stocks. Development of culture techniques began in 1974 with the transfer of 40 wild adults from Lake Mohave to the Willow Beach NFH (Toney 1974). Wild fish were also taken to Dexter NFH where the technology for propagating and raising this species in captivity developed and began to evolve (e.g., Inslee 1981; Jensen 1983; Hamman 1985, 1987).

Initial efforts to raise razorback suckers focused on culture techniques, but it soon became apparent that all aspects of raising and releasing fish were important. Eventually two approaches became apparent: a “broodstock development approach” that produced fish in hatchery settings for release of large numbers of young into the wild; and a “repatriation approach” where wild larvae were captured and raised in protected ponds before releasing the fish at large sizes to avoid predation. These fundamental approaches have been varied and refined extensively to identify the best strategy for enhancing genetic diversity and survival of fish in the wild. A third approach—the "translocation approach"—has recently been implemented and evaluated with the Lake Mead population, where mature wild fish are telemetry tags (i.e., acoustic, sonic, or radio) and translocated to suitable habitat to help locate wild fish and in anticipation of imprinting by their progeny. The following describes these fundamental approaches used to propagate and grow-out razorback suckers.

A-3.1 Broodstock Development Approach

A-3.1.1 CULTURE OF EGGS AND YOUNG

When wild razorback suckers were first taken to Willow Beach NFH in 1974 (Toney 1974), efforts focused on developing culture techniques to successfully procure and fertilize eggs and hatch the young (Inslee 1981; Jensen 1983). It was quickly discovered that sexual maturation of the razorback sucker was more a function of size than age. Hatchery-reared males matured as early as 2 years of age and 355 mm in length while females first produced viable eggs at 3 years of age and about 400 mm in length (Jensen 1983). Females typically became gravid at about 10°C and were ready to spawn at water temperatures of about 12.8°C. Initial culture techniques allowed the females to mature with temperature and they were injected with human chorionic gonadotropin (HCG), and later with carp pituitary extraction, to finalize maturation of the egg mass and to stimulate ovulation. The eggs were incubated in Heath incubator trays at an optimum temperature of about 21°C. Hatching occurred in 96 to 144 hours with a peak at about 120 hours. The newly-hatched larvae are about 15 mm long.

Once the culture techniques were developed and refined for the razorback sucker, plans were developed for Genetics Management Guidelines (Williamson and Wydoski 1994), a Coordinated Hatchery Facility Plan (Wydoski 1994a), and a Genetics Management Plan (Wydoski 1994b). These plans describe the strategies for protecting unique genetic characteristics through planned matings of captured wild fish for broodstock development. Broodstock development is the traditional method for producing large numbers of fish while preserving the genetic diversity of the wild population. As many wild fish as possible are collected and selectively crossed to produce known family lots or pedigrees such that future paired matings avoid crossing siblings or half-siblings. Continued crosses of unrelated fish and infusion of new wild fish lead to the development of a broodstock of genetically diverse adults. Most broodstocks for the razorback sucker number at least 300 adults. Selected individuals from each broodstock are crossed annually to produce the young needed for release to the wild. Cryopreservation techniques have been developed for the razorback sucker to preserve genetic diversity in case of projected losses of certain stocks (Tiersch et al. 1997, 2000).

The recommended breeding strategy for broodstock development for the razorback sucker has been to mate 25 females with 25 males (25 x 25 paired matings) to produce 25 pedigreed family lots (groups of fish unrelated as siblings or half-siblings) (Wydoski 1994a). This strategy is used if sufficient numbers of wild adults are available and removal of fish from the wild will not jeopardize the genetic characteristics of the founder stock. An inbreeding rate of 1% is estimated for an effective population size of 50 fish that is acceptable for maintaining the genetic diversity of wild fish stocks used as founders.

When stocks are low, a minimum breeding strategy involving a 5 x 5 di-allele cross may be used to develop a broodstock. A 5 x 5 breeding strategy has an effective population size of 10 fish and an estimated inbreeding rate of 5%. In the event that 5 males and 5 females are not available, a factorial mating may be used to capture the genetic contribution from all fish of the least numerous sex. Additional wild adults should be used to supplement the broodstock developed from a 5 x 5 or factorial cross when the fish are available to increase the effective population size and reduce the estimated inbreeding rate.

Because the contemporary distribution of the razorback sucker is fragmented by large mainstem dams and reservoirs and by habitat destruction, isolated stocks have been identified for the lower basin (primarily in Lake Mohave and Lake Mead), the upper basin (the Green and Colorado rivers), and the San Juan River. Genetic analyses of fish throughout the system revealed a gradient of highest diversity toward the lower basin fish (Dowling et al. 1996a, 1996b, 2005) with genetic characteristics distinct to certain groups and worthy of protection and preservation. Hence, multiple broodstocks for the razorback sucker have been developed that are derived from fish of a given origin, and general mixing of stocks has been avoided. Broodstocks for the razorback sucker are currently housed at:

- Dexter NFHTC (for Lake Mohave, San Juan River),
- Ouray National Fish Hatchery (for Green, Colorado, San Juan rivers),
- Grand Valley Endangered Fish Facility (for Green, Colorado, San Juan rivers), and
- Wahweap State Fish Hatchery (for Green River).

The manner in which these fish are handled and used for culture is guided by contemporary genetics management plans (Czapla 1999; Crist and Ryden 2003; Dexter NFHTC 2004).

A-3.1.2 GROW-OUT OF YOUNG

When razorback suckers were first hatched in captivity, the young were held in small hatchery troughs and fed commercial fish diets that included pelletized feeds and dried and live brine shrimp. It was soon learned that after hatching and initial feeding in hatchery tanks and raceways, the young fish fared better in fertilized outdoor ponds where they could feed on natural foods of zooplankton (Jensen 1983; Hamman 1985). It was discovered later that this strategy simulated available foods in floodplains used as natural nurseries by the newly-hatched fish (Grabowski and Hiebert 1989; Papoulias and Minckley 1990; Mabey and Shiozawa 1993).

The use of outdoor ponds remains the fundamental strategy for growing and holding razorback suckers. Small ponds (0.1-acre and 0.2-acre) are considered optimal for rearing razorback suckers in family lots to maintain genetic diversity and to reduce handling stress. Although larger ponds can be used to maintain larger marked fish, the use of smaller ponds minimizes stress to the fish during handling for segregated spawning. Also, small ponds warm quickly and promote higher growth than raceways; whereas, raceways have cooler water temperature because they are operated as flow-through systems and they require much more water than ponds. The numbers of fish and biomass in these ponds need to be continually monitored to ensure a balanced feeding regime, optimize metabolic rate, and to ensure adequate dissolved oxygen and avoid build-up of unionized ammonia toxicity. The techniques to grow out young razorback suckers continue to be refined and evaluated to improve growth and especially subsequent survival in the wild.

A-3.2 Repatriation Approach

A repatriation program was initiated in 1990 by a cooperative partnership that became known as the Native Fish Work Group (NFWG; see Marsh et al. 2005 for detailed description). This program was formed from the concern for declining numbers of wild razorback suckers in the lower basin and particularly the Lake Mohave population, where the number of fish was historically in the hundreds of thousands, but by 2002 was believed to be only about 3,000 individuals (Minckley et al. 2003).

Despite evidence of spawning and larval production, juvenile recruitment was failing largely as a result of predation by nonnative fishes (Marsh and Langhorst 1988; Minckley et al. 1991; Marsh and Pacey 2005). Some fish in the population were estimated to be older than 40 years (McCarthy and Minckley 1987), and although still genetically diverse, there was concern over loss of genetic viability in the region of the Colorado River System with the greatest genetic diversity for the species (i.e., Lake Mohave; Dowling et al. 1996a, 1996b).

The repatriation approach was based on prior research that showed low survival of stocked razorback suckers raised in the more traditional hatchery environments. Based in part on the work of Marsh and Brooks (1989), the initial target size for released fish was 250–300 mm TL, which required substantial quantities and reliable sources of larvae and predator-free rearing environments. In the traditional sense, broodstocks were developed and maintained at hatcheries from which eggs were taken and the larvae raised in raceways, troughs, and ponds. This required a large amount of hatchery space and high cost to feed and raise the fish to the target size, which took up to 2 years.

As an alternative to traditional hatchery methods, options were explored to rear larvae in semi-natural environments such as lakeside backwaters or offsite ponds where early efforts continued to have little success. Initially, 200 wild adult razorback suckers were taken from Lake Mohave in 1991 and stocked into lakeside backwaters, stripped of gametes, and the young released into these backwaters. This effort produced about 200,000 embryos that were released into a lakeside backwater but resulted in only 17 juveniles surviving (Minckley et al. 1991; Mueller 1995).

It was felt that the problem was selective breeding of adults, and in 1994, an alternative effort began with collection of wild naturally-produced larvae from inlets and bays around Lake Mohave (Mueller et al. 1993). This effort yielded more than 440,000 larvae between 1990 and 2002 that were subsequently reared in protected lakeside backwaters and offsite grow-out facilities free of nonnative predators. These fish were reared to a nominal target size and nearly 58,000 were released as marked juveniles into Lake Mohave between 1993 and 2002.

Annual estimates of these “repatriated fish” (i.e., fish derived from wild stock, reared in captivity, and stocked into the reservoir) ranged from 1,017 to 2,494 individuals and post-stocking survivorship ranged from 2% to 6% for the period 1999–2002 (Marsh et al. 2005). Total length at release was the most important determinant of post-stocking survival, which more than doubled for releases averaging 350 mm TL compared with those averaging 300 mm TL (see section 2.5.1 for a further description of survival).

The goal of the NFWG was to establish a repatriated population of 50,000 razorback suckers that adequately represented the known historical genetic characteristics of the wild Lake Mohave population. The goal of a “genetic refuge” in Lake Mohave was adopted as part of the demographic criteria for the species recovery goals (USFWS 2002).

A-3.3 Translocation Approach

Biologists in Lake Mead have had recent success catching wild razorback sucker larvae, raising them in captivity, and returning them to the wild as large subadults or adults (Kegerries et al. 2009; Albrecht et al. 2010). A size of ≥ 500 mm TL is recommended and the fish are equipped with telemetry tags to ensure that they can be tracked. Under this approach, telemetered adults are released just prior to spawning so they aggregate with, and show biologists the locations of, additional fish. Progeny produced by these fish are likely to imprint on these areas. This approach of locating existing wild fish with subsequent imprinting of progeny has not been fully evaluated, but shows promise from high survival rates and mixing of translocated fish with spawning aggregations of wild fish.

A-4.0 Transport and Release Methods

A number of methods have been used to transport razorback suckers from grow-out facilities and release them into the wild. The initial transport method was the traditional approach of hauling fish in aerated tanks on hatchery trucks. Some fish are still transported in this manner, especially from the primary culture facilities. Increasingly there has been a trend toward raising fish in local riverside or lakeside ponds where transport distances are reduced, stress to the fish is minimized, and overall survival is increased.

A-4.1 Direct Release

Traditionally and historically, fish transported to a release site were simply released with perhaps only attempts to adjust the temperature of the water in the holding tank to the approximate temperature of the receiving water. Small razorback suckers that have been released directly into receiving waters have experienced low survival, although all factors affecting survival of stocked fish are not fully understood. Larger fish have survived better, but a “fright response” has been identified in fish released into a new and different environment where foreign chemical cues may cause individuals to become frightened and swim great distances in an attempt to locate a more familiar area. Direct release of fish may be effective in confined habitats, but may result in initial long-distance movement of the fish away from targeted restoration areas.

A-4.2 Acclimation

The post-stocking dispersal, habitat use, and behavioral acclimation of young razorback suckers in reservoirs (Mueller and Marsh 1998; Mueller and Burke 2005) show a tendency for recently stocked fish to move considerable distances from release sites and the need to acclimate the fish. Holding the fish in cages for a short time before release appears to minimize a “fright response” and reduces the dispersal of these fish following release. Currently, the SJRIP is experimenting with short-term acclimation (i.e., < 48 hours) to reduce dispersal and short-term mortality.

The prospect of using imprinting by razorback suckers as a strategy for coaxing fish to return to certain areas was explored in the late 1980’s. Thyroxine concentrations and chemical imprinting of razorback suckers at Dexter NFHTC showed that the species will imprint at the larval stage on chemicals including morpholine (Scholz et al. 1993). Further tests on chemical imprinting have not been performed on the species.

A-5.0 History of Razorback Suckers Released

A-5.1 Lower Colorado River Basin

Razorback suckers have been stocked in the Lower Colorado River Basin since 1980 and in the Upper Colorado River Basin since 1995. Altogether, about 14.3 million razorback suckers were stocked in the lower basin from 1980 through 2004 (Table A-2). The numbers of fish stocked per year quickly exceeded a million fish, and from 1982 to 1988, nearly 13.9 million fish were stocked at a rate of 560,232 to 3,183,235 fish per year. Stocking of razorback suckers in the lower basin became more widespread starting in the late 1990s, with the requirement to stock 25,000 young fish into Lake Havasu and 50,000 into Lake Mohave for a 5-year period to meet the conditions of a 1997 USFWS Biological Opinion on Lower Colorado River operations and maintenance (USFWS 1997).

From 1982 to 1988, a period when the largest numbers of razorback suckers were stocked in the lower basin, the average size of fish stocked was 16 to 30 mm TL (Figure A-3). These fish were mostly recently-hatched larvae and post-larvae that were a few days to a few weeks old. Starting in 1989, the average size of razorback suckers stocked began to increase and remained greater than 100 mm TL, except for the fish stocked in 1992 and 1996, which averaged about 80 mm TL. Also starting in 1989, the numbers stocked per year dropped below 100,000 fish. From 1997 to 2004, the average size of razorback suckers stocked exceeded 280 mm TL and was as great as 342 mm TL in 2004 when 25,679 fish were stocked.

Table A-2. Numbers of razorback suckers stocked annually into the Lower Colorado River Basin (1980-2004), mean total length (TL), and estimated number of first-year survivors. Table adopted from Schooley and Marsh (2007).

Year	Lake Mead	Lake Mohave	Lake Havasu	Lower River	Central Arizona Waters	Sum All Sites	Mean TL (mm)	Survivors (%)
1980				79		79	334	20.25
1981					7,000	7,000	81	0.09
1982					612,627	612,627	18	0.02
1983				457	2,664,296	2,664,753	16	0.02
1984					3, 183,235	3,183,235	16	0.02
1985				57	3,026,687	3,026,744	18	0.02
1986			466,923	1,045,271	718,531	2,230,725	30	0.04
1987				1,276,367	334,018	1,610,385	28	0.04
1988				1,700	558,532	560,232	30	0.09
1989				1,375	79,680	81,055	103	1.02
1990				3,039	7,228	10,267	242	6.46
1991					3,968	3,968	197	1.81
1992		10,899			207	11,106	84	0.74
1993		1,358	1,949	14,006	1,120	18,433	141	5.55
1994		2,195	6	81	3,493	5,775	320	26.3
1995	40	1,501	9,888	13,514	3,156	28,099	129	2.17
1996		3,094	91	70,165	5,963	79,313)	81	1.43
1997	6	7,317	986	2,000	1,641	11,950	283	10.57
1998	11	7,667	9,332	62	2,391	19,463	321	16.91
1999	39	20,166	6,358	2,421	2,000	30,984	294	10.97
2000		7,215	4,634	4,380	2,131	18,360	310	14.47
2001	9	15,392	6,784	4,425	1,574	28,184	318	15.41
2002	23	11,747	30	15,548	2,022	29,370	299	11.22
2003	12	19,638	142	14,070	378	34,240	313	14.22
2004	6	13,479		9,869	2,325	25,679	342	23.58
All years	146	121,668	507,123	2,478,886	11,224,203	14,332,026		0.27
dTL	444	286	32	27	23	26		
Survival (%)	65.07	12.53	1.38	0.28	0.09	0.27		

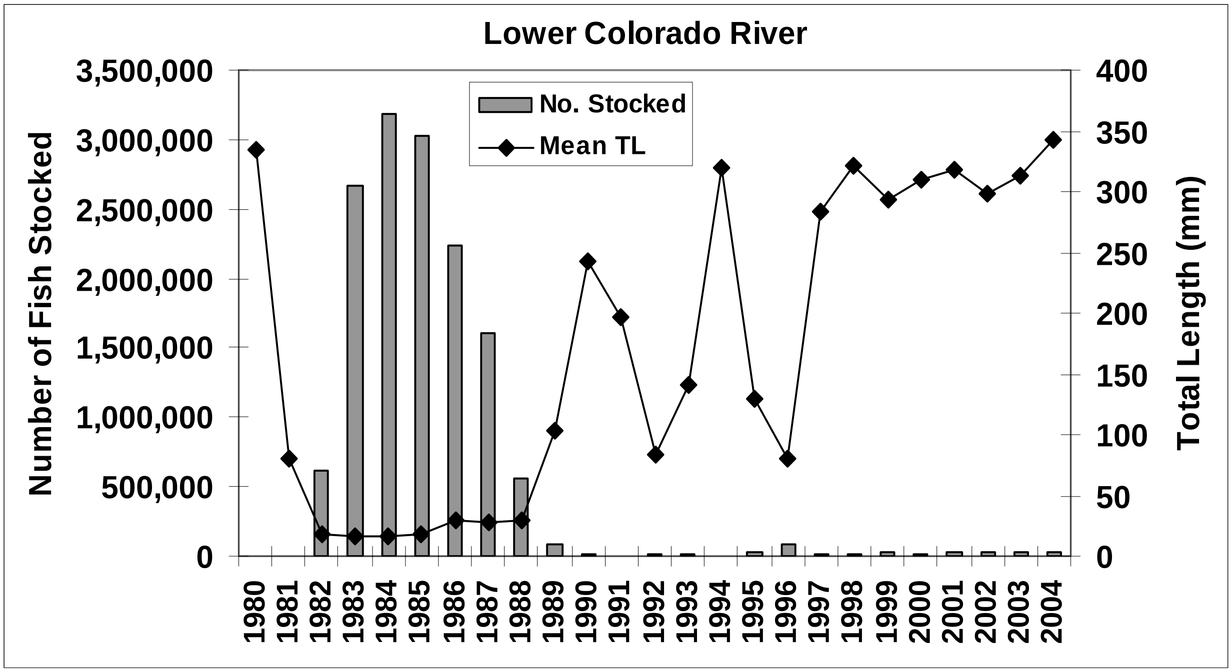

Figure A-2. Total numbers and mean total lengths (shown above bars) of razorback suckers stocked in the Lower Colorado River Basin, 1980-2004. See Table 2 for details on numbers and fish lengths.

A-5.2 Upper Colorado River Basin

From 1995 to 2010, nearly 280,000 razorback suckers of various sizes were stocked into the Colorado, Gunnison, and Green rivers of the Upper Colorado River Basin (Table A-3; Figure A-4). From 1995 to 2001, a total of 49,108 fish were stocked under an Experimental Stocking Plan (Burdick et al. 1995). In 2002, 11,648 fish were stocked under the State Stocking Plans for Colorado (Nesler 2001) and Utah (Hudson 2001); and from 2003 to 2010, 218,409 fish were stocked under an Integrated Stocking Plan (Nesler et al. 2003). These stocking plans identify the numbers of razorback suckers that should be produced in hatchery facilities to meet stocking numbers that are believed to lead to species recovery. The majority of these fish were raised in captivity with the methods and techniques described in section 2.2.1 under a broodstock development approach. Of 279,165 fish stocked, a total of 2,277 were recaptured as of 2008. Section 2.5.2 describes survival rates of select stocks of these fish.

In addition to the fish stocked in the Colorado, Gunnison, and Green rivers, a total of 58,916 razorback suckers were stocked in the San Juan River during 1994-2008 (Table A-4, Figure A-5). Average sizes of these fish varied from 192 mm TL to 424 mm TL. The full range of sizes stocked was 68 mm TL to 573 mm TL. Unlike the lower basin, there was no distinct pattern in sizes of razorback suckers stocked, although a greater proportion of large fish is generally being stocked in all rivers of the upper basin.

Table A-3. Numbers of razorback suckers stocked annually into the Colorado, Gunnison, and Green rivers (1995–2010) and numbers recaptured. Source: Upper Colorado River Endangered Fish Recovery Program.

Year	Stocking Goal	Colorado, Gunnison	Middle Green	Lower Green	Sum All Sites	Recaptures	
						Colorado, Gunnison	Green
1995	13,100[1]	316	--	--	316	--	--
1996	13,100[1]	1,112	--	--	1,112	--	--
1997	13,100[1]	2,926	--	--	2,926	0	3
1998	26,200[1]	606	387	--	993	1	0
1999	58,600[1]	6,155	1,357	--	7,512	0	31
2000	104,800[1]	29,826	224	--	30,050	24	10
2001	104,800[1]	6,199	--	--	6,199	31	41
2002	34,940[2]	11,374	--	274	11,648	3	20
2003	3,310 & 9,930[3]	5,541	8,446	2,377	16,364	157	13
2004	3,310 & 9,930[3]	6,153	9,619	5,957	21,729	121	32
2005	3,310 & 9,930[3]	10,284	4,850	4,231	19,365	361	101
2006	3,310 & 9,930[3]	10,726	5,021	15,188	30,935	15	412
2007	3,310 & 9,930[3]	10,064	7,749	8,549	26,362	32	225
2008	3,310 & 9,930[3]	12,949	11,677	10,161	34,787	314	330
2009	3,310 & 9,930[3]	17,975	14,983	5,017	37,975	--	--
2010	3,310 & 9,930[3]	9,926	10,926	10,040	30,892	--	--
Totals:		142,132	75,239	61,794	279,165	1,059	1,218

[1]Experimental Stocking Plan (Burdick et al. 1995); fish stocked in various size ranges
[2]State Stocking Plans for Colorado (Nesler 2001) and Utah (Hudson 2001)
[3]Integrated Stocking Plan: 3,310 in each of 3 reaches in Colorado and Gunnison rivers; 9,930 in each the middle and lower Green River (Nesler et al. 2003)

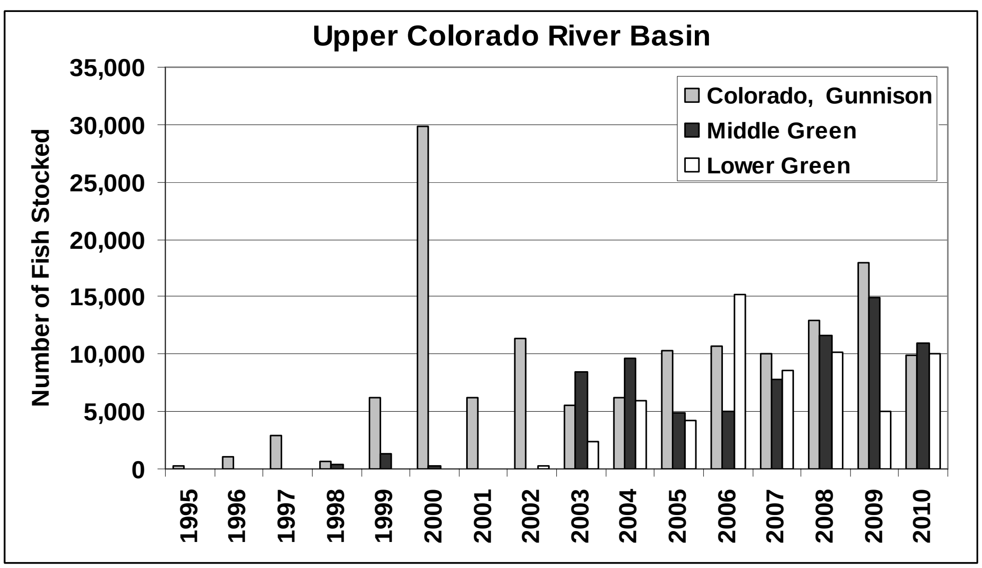

Figure A-3. Total numbers of razorback suckers stocked in the Upper Colorado River Basin, 1995-2010. See Table 3 for details on numbers.

Table A-4. Numbers and sizes of razorback suckers stocked annually into the San Juan River (1994-2008). Table from Furr and Davis (2009).

Year	# Stocked	Mean TL (mm)	Range TL (mm)
1994[1]	688	251	100-446
1995[1]	16	424	397-482
1996[1]	238	336	204-434
1997[2]	2,883	192	104-412
1998[2]	1,275	250	185-470
1999	0	--	--
2000[2]	1,044	214	111-523
2001[2]	688	410	288-560
2002[3]	140	319	110-470
2003[3]	887	327	100-495
2004[3]	2,988	353	225-559
2005[3]	1,996	355	223-534
2006[3]	18,793	265	68-537
2007[3]	22,836	268	110-573
2008[3]	4,444	297	225-390
Totals:	58,916	304	68-573

[1]Experimental Stocking Plan: 1994-96 (Ryden and Pfeifer 1994)
[2]Five Year Augmentation Plan: 1997-2001 (Ryden 1997)
[3]Augmentation Plan: 2002-2008 (Ryden 2003, 2005)

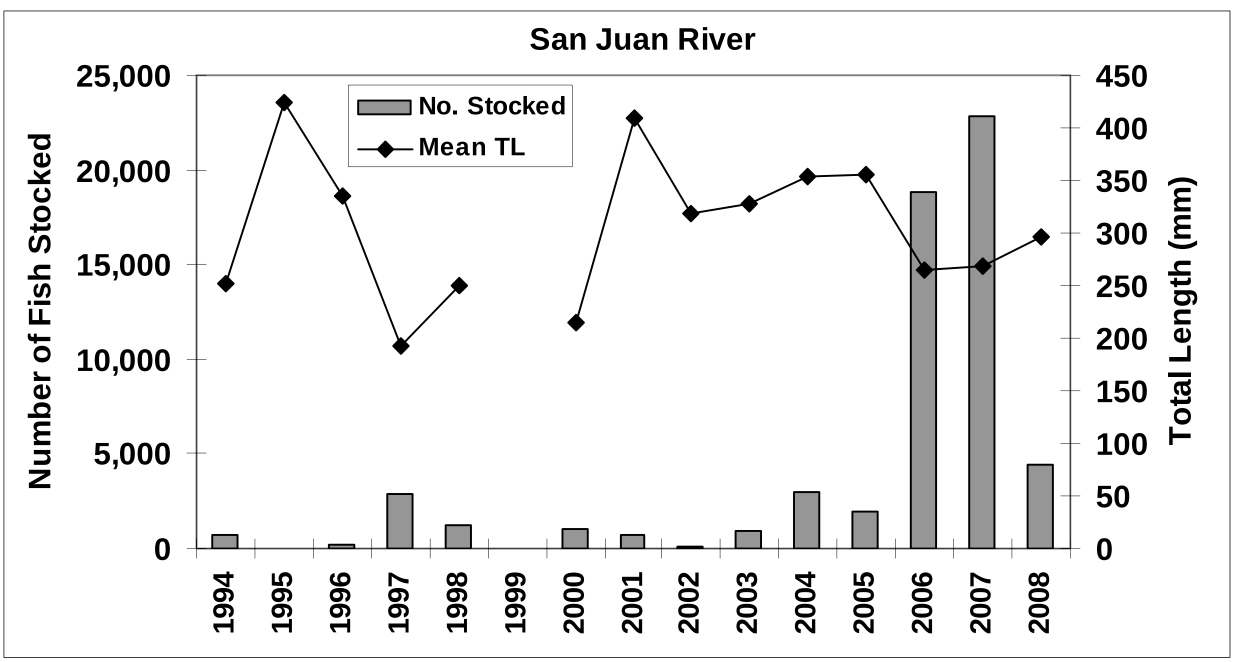

Figure A-4. Total numbers and mean total lengths of razorback suckers stocked in the San Juan River, 1994-2008. See Table 4 for numbers and fish lengths.

A-6.0 Survival of Razorback Suckers Released

A-6.1 Lower Colorado River Basin

The survival of razorback suckers released into the wild has not been evaluated until recently. For years, large numbers of fish were stocked and it was presumed that at least some proportion would survive to justify the effort. However, the numbers of recaptured fish remained low and it became evident that strategies were needed for evaluating survival of stocked fish.

In one of the most extensive survival assessments of stocked razorback suckers in the lower basin, Schooley and Marsh (2007) estimated that first-year survival of fish less than 100 mm TL was less than 1% (Table A-2). For fish stocked at mean total lengths greater than 100 mm, first-year survival was as high as 24%. Regardless of release size, estimated annual survivorship was less than 30%, although there was a clear relationship between survival and size at stocking (Figure A-6). Evidence of long-term survival was rare, indicating that population augmentation through stocking failed to replace lost wild populations or establish new ones of significant size. Continued stocking to the lower basin was not recommended because threats were substantial and conditions were not conducive to long-term survival of stocked fish. Instead, starting in about 1997, population augmentation was recommended for "repatriated habitats" (see section 2.2.2) that were depleted or devoid of predators. However, even predator-free habitats did not mitigate avian predation, and appropriate control measures were also advocated for piscivorous birds. Primary mortality factors for these stocked fish were attributed to piscine (fish) and avian (bird) predators. Piscine predation was ubiquitous in all stocked sites, and predation was sufficient to impact stocked populations throughout even when predator abundance was low (Schooley and Marsh 2007).

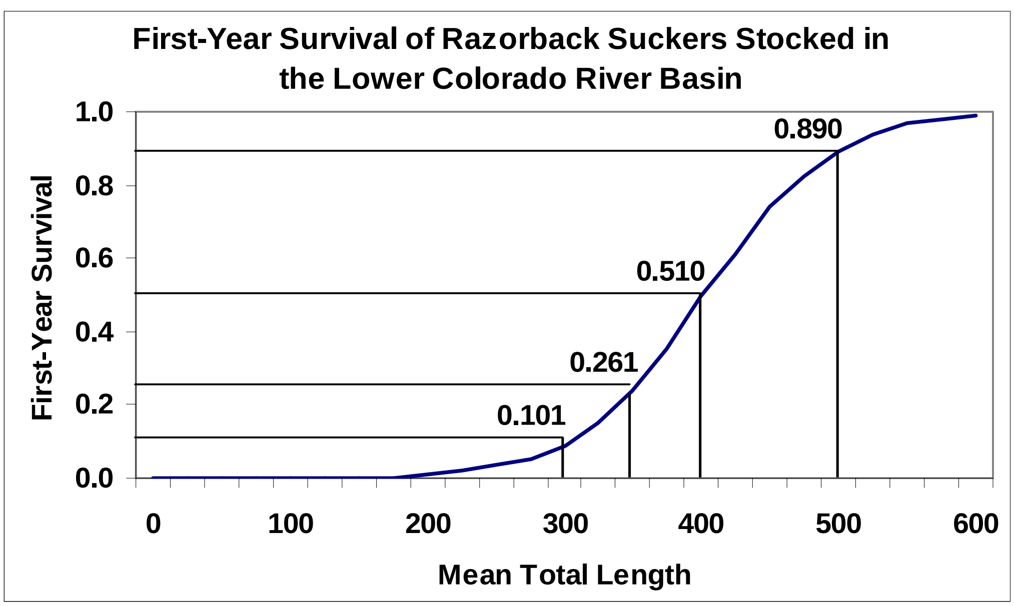

Figure A-5. First-year survival curve as a function of total length at release for repatriated razorback suckers that were recaptured as adults during annual March censuses in Lake Mohave, Arizona-Nevada, 1992-2002. Survival is shown for lengths of 300, 350, 400, and 500 mm TL. Figure reproduced from Marsh et al. (2005).

A-6.2 Upper Colorado River Basin

A study of survival of several size classes of stocked razorback suckers (Burdick 2003) showed that of nearly 50,000 fish stocked in 1994–2000, only 84 (0.2%) were recaptured after being at large ≥ 6 months after stocking. An overview of the stocking program (Francis and McAda 2006) summarized stocking and capture records throughout the basin from 1995–2005 and reported similar low survival rates for stocked fish. An integrated stocking plan (Nesler et al. 2003) was developed for the Upper Colorado River Basin as guidance for hatchery production of fish and releases to the wild. Variations and combinations that involve the use of ponds and hatchery tanks were implemented to maximize survival of stocked fish in the wild.

An analysis of hatchery-reared razorback suckers stocked from 1995–2005 in the Green and Colorado River subbasins (Zelasko 2009; Zelasko et al. 2010) found that survival in the first year was considerably lower than rates assumed in the integrated stocking plan: 0.05 actual survival (mean TL = 252.5 mm, averaging across season of stocking) vs. 0.50 assumed survival (for a similar sized age-2 fish). First-interval survival was positively related to total length at time of stocking, but razorback suckers of nearly all lengths survived at significantly lower rates when stocked during summer compared to any other season. After their first interval in the river, hatchery-reared razorback suckers survived at a rate similar to the adult rate assumed in the integrated stocking plan (i.e., 0.75 vs. 0.70).

In an attempt to experimentally control potential factors that might affect survival, fish were raised at the Grand Valley EFF and the Ouray NFH and subsequent survival was evaluated with three basic methods during 2004–2007 (Zelasko et al. 2011). To begin the experiment, fish were raised in the hatchery from incubation (April to May) until grading (May to August), at which time the fish were graded by size. The smallest fish were moved to outdoor rearing ponds until release (August to October of the following year). The ponds varied in size (surface acreage and depth) and consisted of leased or donated gravel pits as well as ponds built for fish culture. The gravel pits were used to condition fish to variable water conditions and natural diets, whereas the fish culture ponds were more controlled and supplemented with fish food pellets.

The largest-graded fish remained in the hatchery until the following spring (March to May), when most were moved to ponds until release (August to October) and the remainder stayed in hatchery tanks until release (July to September). These fish were used to evaluate survival under each of the following three methods:

- **Pond Fish**: Fish raised under the two pond-rearing methods that spent any amount of time (approximately 6 months to 1 year) in outdoor rearing ponds.
- **Tank Fish**: Fish that were reared solely in hatchery tanks.
- **Intensive Fish**: Fish that upon swim-up were moved as larvae from hatchery tanks to outdoor ponds (with both natural food and supplemental pellets), where they remained until early autumn. The fish were then harvested and moved inside to hatchery tanks to increase over-winter growth, and in spring, they were returned to outdoor ponds, where they were PIT-tagged and remained until harvest and release in autumn.

The mean first-year survival of these hatchery-reared fish was low for each of the three methods: 0.03, 0.05, and 0.08 for tank-, pond-, and intensively-reared fish, respectively (Zelasko et al. 2011). However, survival after their first year in the river was high (0.75–0.94), depending on the interval and rearing method.

Zelasko et al. (2011) also reported that length at stocking and 1st-year survival were positively correlated (Figure A-7). Survival of fish (reared by any method) smaller than 200 mm TL approached zero but increased to an average of 0.83 for the few fish that were stocked larger than 500 mm TL. Mean 1st-year survival of fish averaging 301.5 mm TL was 0.09, but increased to about 0.40 and higher for fish 400 mm TL. Season of stocking also had an effect on 1st-year survival; survival of fish 301.5 mm TL stocked in summer were 0.03, 0.03, and 0.04 for tank-, pond-, and intensively-reared fish, respectively. Stocking in spring produced the highest mean estimated survival rates of 0.20 and 0.29 for pond- and intensively-reared fish, respectively.

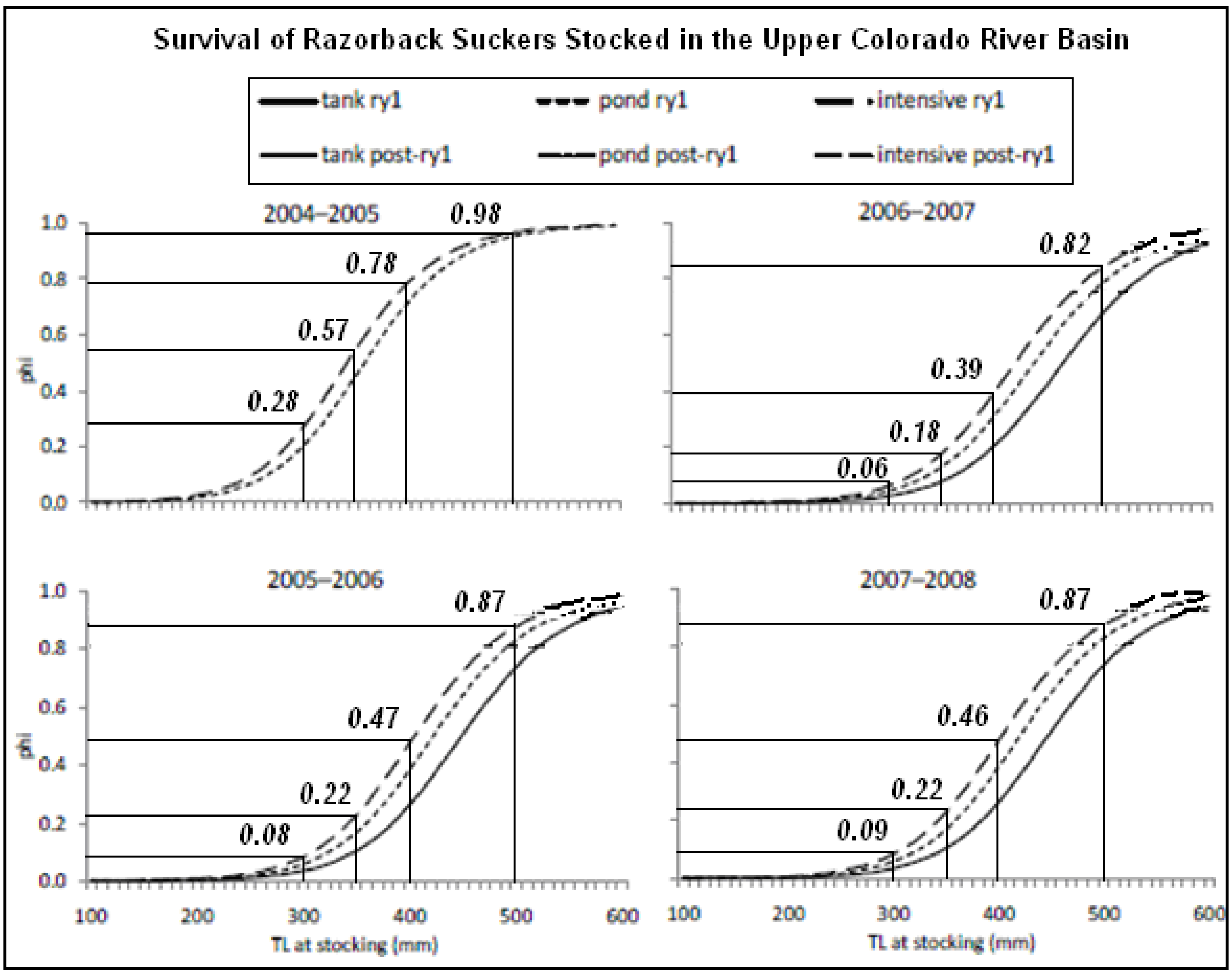

Figure A-6. Total length (TL)-dependent, 1st-interval (ry1) and subsequent-interval (post-ry1) survival rate estimates for razorback suckers reared by three methods and stocked into the Upper Colorado River Basin, Utah and Colorado, 2004–2007. Interpolated survival rates are shown for lengths of 300, 350, 400, and 500 mm TL. Figure reproduced from Zelasko et al. (2011).

In comparing survival rates of razorback suckers stocked in the lower and upper basins (Figures A-6 and A-7), it becomes apparent that the grow-out method, the size of fish at stocking, and the season of stocking are the principal drivers of survival. The general relationship of survival for the two basins is strikingly similar, as are the survival rates at different fish sizes. Survival rate of fish released in the lower basin more than doubled from 0.101 to 0.261 for sizes of 300 mm and 350 mm TL, respectively. For the various methods used in the upper basin, survival of fish 300 mm TL was generally less than 0.1, but was more than double (0.18–0.57) for fish 350 mm TL. Survival rates of fish released at 400 mm and 500 mm TL in the lower basin were 0.51 and 0.89, respectively, while rates of fish raised under intensive care in the upper basin were as high as 0.78 and 0.98, respectively. This information shows that there is a substantial increase in survival of fish stocked at a larger size, especially fish larger than 350 mm TL, and that preferred stocking size should be 400 mm to 500+ mm.

A-7.0 Evaluation of Culture and Augmentation Methods

A large number of methods and variations have been employed in the propagation, grow-out, and release of razorback suckers into the wild (Table A-5). The single greatest measure of success is the apparent or measured survival rate of stocked fish for the various methods. The two factors that most appear to affect survival in the wild are: (1) grow-out method and (2) size of fish at release. In both the lower basin and the upper basin, the most successful grow-out methods are: (1) repatriation in which wild larvae are raised in protected, predator-free environments, and (2) intensive methods in which fish are raised in tanks and ponds to maximize growth and survival. Fish are also being introduced into new areas through a translocation approach in which adults are taken from wild populations or refuges and released just prior to spawning with the potential benefit of imprinting by produced larvae to the new environment.

When considering the potential for release of razorback suckers into the lower Grand Canyon, the methods described and evaluated in Table 5 become relevant in the following manner (see section 3.0 for Recommended Augmentation Strategy):

1. **Release Large Numbers of Young:** Large numbers of larvae or young will almost certainly have a low survival rate if stocked in the lower Grand Canyon. There are no protected predator-free habitats in this area and food resources for young may be limited to backwater habitats. The river currents will likely transport most of these fish into Lake Mead where there are large numbers of predators. There is also the risk of affecting the genetic integrity of the wild Lake Mead population if even small numbers of fish from selective breeding were to survive.
2. **Release Moderate Numbers of Juveniles:** Juveniles are also likely to have a low survival rate in the lower Grand Canyon because of the riverine-like environment and the large numbers of predators that otherwise have an advantage over naïve hatchery-reared fish.
3. **Release Large Subadults or Adults:** Large fish of preferably wild origin are the most likely to have the highest survival rate in the lower Grand Canyon, and are the least likely to disrupt the genetic integrity of the Lake Mead population.

Table A-5. Description and evaluation of propagation, grow-out, and release methods for the razorback sucker.

Method	Description	Evaluation
	Propagation and Grow-Out	
➢ Broodstock Development (hatchery broodstock developed from wild fish; Larvae produced from selective paired matings)	Tanks • Larvae raised in hatchery tanks.	Larvae raised in hatchery tanks must be fed an artificial diet that may slow growth and proper development otherwise realized with natural foods.
	Ponds • Larvae hatched indoors and moved to outdoor fertilized earthen ponds.	Larvae raised in ponds are exposed to a naturalized environment with natural foods that helps to develop feeding strategies and possibly coping with competition and predation.
	Intensive (Tanks and Ponds) • Larvae raised in hatchery tanks and moved to outdoor ponds (with both natural food and supplemental pellets), where they remained until early autumn. • Fish harvested and moved inside to hatchery tanks to increase over-winter growth. • In spring, fish returned to outdoor ponds, PIT-tagged, harvested and released in autumn. These were labeled "intensive" fish.	This approach has resulted in the highest survival rate for fish stocked at sizes of greater than about 300-350 mm TL. Fish raised in ponds are exposed to a naturalized environment with natural foods that help to develop feeding strategies and possibly coping with competition and predation. Fish taken indoors increase their over-winter growth and survival and have better survival when released in the wild.
➢ Repatriation (fish derived from wild stock, reared in captivity, and stocked into the reservoir)	Lakeside Ponds • Wild adults held in lakeside ponds and their larvae released back to the reservoir. • Wild larvae collected and raised in lakeside ponds to 300 mm TL and released in reservoir. • Wild larvae collected and raised in lakeside ponds to 350 mm TL and released in reservoir.	Larvae collected from natural reproduction are presumed to have high genetic diversity, but have low survival because of predation from especially nonnative fish. The survival and growth of these larvae are greatly enhanced when raised in protected predator-free environments, but they continue to be susceptible to predation if released less than about 350 mm TL. These findings are consistent with survival of upper basin stockings in which survival is greater for fish larger than about 350 mm TL.
➢ Translocation (wild fish located in new area for imprinting by young)	No Artificial Holding Areas • Wild fish tagged with telemetry and located in new area for imprinting by young.	

Method	Description	Evaluation
Transport and Release		
➢ Direct release (fish are transported and released directly on-site)	No Acclimation • Fish are released directly into receiving waters (except for thermal tempering of transport tank).	Fish released directly into the wild tend to move long distances immediately after release. This may be undesirable if the goal is to keep fish in the area stocked.
➢ Acclimation (fish are handled to minimize long-distance dispersal from the release site)	Cages • Fish are held in cages in receiving water to minimize "fright response".	The "fright response" has been documented for various fish species released into the wild. Holding the fish at the release site in cages helps the fish to acclimate to the new water and to become calmed from the stress of transport and release.
	Chemicals • Larval are exposed to chemicals for imprinting at an early age, and chemicals are used at release sites to cue the fish.	Larval razorback sucker have been shown to respond to chemicals (i.e., imprint) such as morpholine, but only one study has been conducted and further evaluation is needed before chemicals can be considered to imprint razorback suckers.

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