Reclamation

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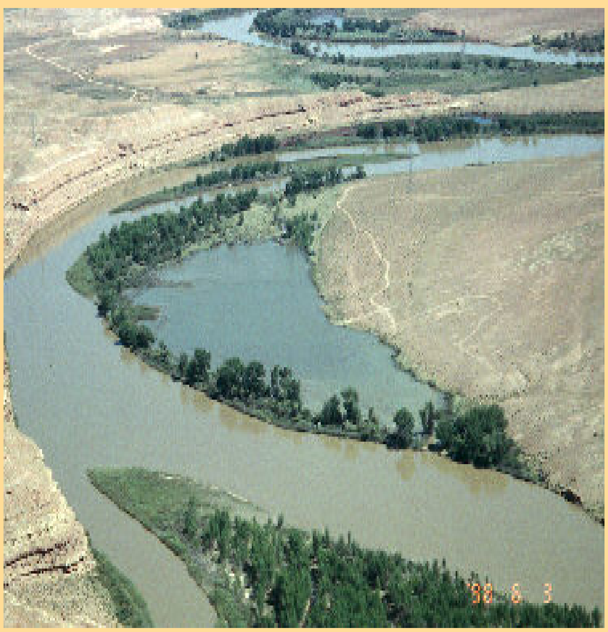
Review and Summary of Razorback Sucker Habitat In the Colorado River System



SWCA ENVIRONMENTAL CONSULTANTS

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Cover Photos:

Top center: Cross Butte at RM 35 of the Green River (R. Valdez, 1986); *top left:* aerial view of riverside floodplain above Brennan at RM 269 on the Green River (USFWS, April 2000); *bottom left:* adult razorback sucker captured in the Upper Colorado River near Grand Junction (R. Valdez, June 1980); *bottom right:* aerial view of Colorado River in Canyonlands National Park (R. Valdez, December 1980).

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Report Number 1

REVIEW AND SUMMARY OF RAZORBACK SUCKER HABITAT IN THE COLORADO RIVER SYSTEM

Final Report

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

REPORT BY SWCA ENVIRONMENTAL CONSULTANTS
FLAGSTAFF, ARIZONA

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APRIL 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 first 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.

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 reviews and summarizes the habitat used by the species in the Colorado River System. The information contained in this report and two other reports (Science Panel Report and Establishment Strategy) will assist Reclamation and the USFWS in the decision to develop an augmentation plan and release razorback suckers into the lower Grand Canyon. 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.

The razorback sucker is a highly adaptable fish species capable of using a wide variety of habitats. It is endemic to the Colorado River System where it has managed to survive for nearly 2 million years in perhaps the most variable and rigorous hydrological, chemical, and biological environment of any river in North America. This document provides an assimilation of habitat information and data for various life stages of the razorback sucker from throughout its range. Altogether, 84 scientific reports and publications were used as sources for habitat information from five regions of the System, including (1) the Green and Yampa rivers; (2) upper Colorado and Gunnison rivers, including Lake Powell; (3) San Juan River; (4) lower Colorado River, including the Grand Canyon, Lakes Mead, Mohave, and Havasu; and (5) the Gila, Salt, and Verde rivers.

In the middle Green River, the species spawns on cobble/gravel bars in canyon-confined reaches and its larvae drift downstream to nurse and rear in large floodplains that are connected to the river by spring runoff. In the upper Colorado River and lower Gunnison River, it also uses main channel cobble/gravel bars for spawning, but it may use manmade features such as gravel pits as nurseries for young and for resting and rearing. In the San Juan River, it uses complex channel areas for spawning and the larvae may use small backwater-like habitats for rearing, as well as the inflow to Lake Powell. In the lower Colorado River Basin, razorback suckers were once abundant in the expansive floodplains complexes that formed with spring floods, but flood control and irrigation projects have disconnected and eliminated most of these floodplains, and some razorback suckers survive in reservoirs formed by the mainstem dams. The spring-time flows of the historic Colorado River inundated vast bottomlands, particularly in the lower basin, that provided rich productive habitats for the species and established large lake-like features as a component of the species' evolutionary environment. Today, the largest remaining numbers of wild razorback suckers are found in lakes Mohave, Mead, and Havasu, where adults successfully spawn along cobble shorelines and shoals, but where survival of young is low primarily because of large numbers of nonnative predaceous fish. In the Salt and Verde rivers, some stocked individuals have been able to persist in streams with only a fraction of the water volume of the larger riverine habitats.

Razorback suckers occur and persist in rivers, streams, and reservoirs of the Colorado River System as testimony to their adaptability to various habitat conditions. The species has

demonstrated an ability to establish self-sustaining populations in reservoirs, despite the presence of large numbers of nonnative fish predators. In Lake Mead, where shoreline spawning and nursery areas provide vegetation or turbidity as cover from predators, the population is successfully recruiting and appears to be sustained at low numbers that altogether ranged from a low of 91 adults in 2003–05, to a high of 413 in 2005–07. Spawning by this population occurs near inflows of tributaries or washes where turbidity and vegetation are present; i.e., Las Vegas Wash, Echo Bay, and Muddy River/Virgin River inflow. Since the year 2000, larvae and adult razorback suckers have also been found in the Colorado River inflow at the lower end of the Grand Canyon; including sonic-tagged adults moving from one of the three populations. A confirmed spawning site was located in 2010 about 10 mi downstream of Pearce Ferry, which is the lower end of the Grand Canyon.

Expansion of the Lake Mead population into the Colorado River inflow could mean that some razorback suckers are currently using the lower Grand Canyon. However, numerous fisheries investigations through the Grand Canyon, starting about the time that Glen Canyon Dam was completed in 1963, have yielded few razorback suckers. Since 1944, only 10 razorback suckers have been reported from the Grand Canyon, including one from Bright Angel Creek, four from the mouth of the Paria River, one near Shinumo Creek, and four from the mouth of the Little Colorado River. All of these fish were adults, and no razorback suckers have been captured since 1990. Most fisheries surveys of the Grand Canyon have ended at Diamond Creek, and only one survey in the mid-1990s and one in 2005, extended downstream of Diamond Creek to Pearce Ferry. These sampling efforts have failed to catch any razorback suckers, but the species could be present in such small numbers that the likelihood of catching an individual is low.

A formal quantitative assessment of habitat for the razorback sucker in the lower Grand Canyon has not been conducted. An informal evaluation in 2009 showed that the major mesohabitat features used by the species in other river reaches were present, including deep runs, eddies, riffles, and backwaters. This suite of mesohabitats was similar to that used by 12 radio-tagged adults in the lower Grand Canyon in 1997. An additional visual evaluation of the area in 2010 also showed that there are at least three large alluvial cobble/gravel bars similar to those used for spawning in the Green, upper Colorado, and San Juan rivers. These are located at the mouths of Diamond Creek, Spencer Canyon, and Salt Creek. The habitat feature used by the razorback sucker that is absent from the lower Grand Canyon is floodplains that are used by larvae as nurseries. Large off-channel embayments occur at the mouths of Surprise Canyon, Lost Creek, Burnt Spring Canyon, and Ticanebitts Canyon, but these are blocked from the main river channel by large sand berms deposited when Lake Mead was at a higher lake level. The lower Grand Canyon is a remote region of the Colorado River where it would be impractical to access with earth-moving equipment for reconnection of these bays with the main river.

Larval razorback suckers may use small backwaters as nurseries, as in the San Juan River, but most use the larger floodplains. Alternatively, larvae hatched at one of the three cobble/gravel bars in the lower Grand Canyon would only have to drift about 32 to 55 mi, or for an estimated 13 to 22 hr, before reaching the Colorado River inflow to Lake Mead where larvae were found in 2000, 2001, and 2010. Studies in the Green River have shown that these distances are common for larvae drifting from spawning bars to nursery floodplains.

This review of razorback sucker habitat indicates that conditions for subadults and adults are suitable in the lower Grand Canyon. However, there is an absence of floodplains typically used as nurseries by larvae and young, although there are small ephemeral backwaters such as used by young in other parts of the basin. Spawning bars similar in appearance to bars used in other rivers are present at Diamond Creek, Spencer Canyon, and Salt Creek. Over 20 backwaters may be present (depending on river flows) between Lava Falls Rapid (RM 180) and Dry Canyon (RM 265). These backwaters are presently used by large numbers native flannelmouth suckers (*Catostomus latipinnis*) and could be used by larvae and young of razorback suckers. The distances from these potential spawning bars in the lower Grand Canyon to capture sites of larvae in the Lake Mead inflow are less than 60 mi, which is similar to drift distances of larvae in the middle Green River.

1.0 INTRODUCTION

1.1 Background

This report summarizes the habitat information for the endangered razorback sucker (*Xyrauchen texanus*) throughout its range in the Colorado River System. It describes the physical, chemical, and biological attributes used by the species 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 the Colorado River inflow to Lake Mead, where the U.S. Bureau of Reclamation (Reclamation) has initiated an investigation of the potential to improve the status of the razorback sucker. This report and two companion reports (Science Panel Report [Valdez et al. 2012a] and Establishment Strategy [Valdez et al. 2012b]) will assist Reclamation, in collaboration with the U.S. Fish and Wildlife Service (USFWS), to determine if augmentation of the razorback sucker is appropriate and necessary for enabling the species to become established in the lower Grand Canyon.

1.2 Species Description

The razorback sucker is a large catostomid fish that is endemic to the Colorado River System (Minckley et al. 1991). Adults attain a maximum size of about 1 m total length (TL) and a weight of 5–6 kg (Minckley 1983). The body is fusiform and the ventral sucker-like mouth is designed to feed on a variety of insects, crustaceans, and detrital matter. The body is dark, greenish-gray above and the belly and underside are yellowish-white. A cartilaginous ridge forms along the back of adults that gives the species its characteristic appearance and name (Figure 1).

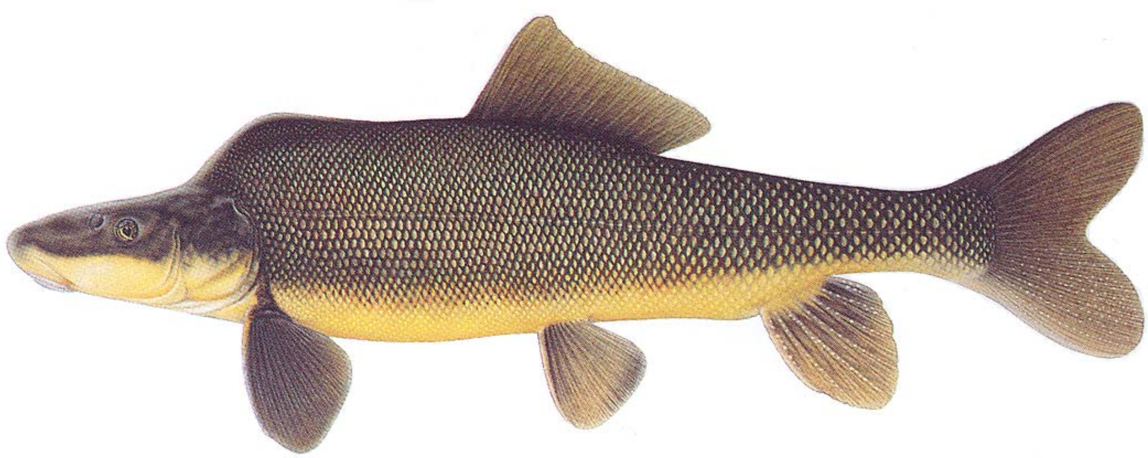

Figure 1. Adult razorback sucker. Illustration by Joseph Tomelleri.

1.3 Status

The razorback sucker is currently designated as "endangered" under the Endangered Species Act of 1973, as amended (ESA; 16 U.S.C. 1531 *et. seq.*), under a final rule published on October 23, 1991 (56 FR 54957). A recovery plan was approved on December 23, 1998 (USFWS 1998), and Recovery Goals were approved on August 1, 2002 (USFWS 2002). The final rule for determination of critical habitat was published on March 21, 1994 (59 FR 13374), and final designation became effective on April 20, 1994 (see Figure 2).

1.4 Historical Distribution

Detailed descriptions of the historical distribution of the razorback sucker are provided by Minckley (1983), Bestgen (1990), and Minckley et al. (1991). The razorback sucker was once widely distributed at elevations of up to about 5,500 ft in rivers and major tributaries of the Colorado River System from Wyoming to northwestern Mexico (Figure 2). It was typically found in calm flat-water reaches and was historically uncommon in swift and turbulent canyon reaches. The species was once abundant downstream of present-day Lake Mead, particularly near Yuma, Arizona (Gilbert and Scofield 1898), and it was common in the Salton Sea (Minckley 1983). River impoundment, flow depletion, and increasing water salinity led to the extirpation of the species in this portion of the lower basin (Everman 1916; Coleman 1929).

The historical distribution of the species has been reduced by about 80% primarily by the construction of major dams along the Colorado River (e.g., Hoover Dam in 1935, Parker Dam in 1938, Davis Dam in 1951, and Glen Canyon Dam in 1963) and the Green River (Flaming Gorge Dam in 1962). These dams have fragmented the historical range of the razorback sucker and altered the river environment by reducing temperature, turbidity, and seasonal flow fluctuations. Dams of the Aspinall Unit (built in 1966–1976) on the Gunnison River are upstream of historical range but these further altered flow conditions in occupied reaches of the Gunnison and upper Colorado rivers, as did Navajo Dam (completed in 1963) on the San Juan River.

Riverine habitat of the razorback sucker was further altered by channelization, diversion of water for agriculture, and the construction of dikes and levees that reduced connectivity between floodplain habitats and the main channel. Disconnection of floodplains reduced nutrient loads to the river (Junk et al. 1989) and severed access to larval nursery habitats (Tyus 1987). The biotic environment was affected by changes in ecosystem processes that affected food supplies and by the proliferation of nonnative fish predators (Miller 1961; Mueller and Marsh 2002).

By the 1960s, the distribution, abundance, and recruitment of the razorback suckers were already markedly reduced in both the upper and lower Colorado River basins (Minckley et al. 1991). The largest river population remained in the middle Green River, Utah, and sizeable reservoir populations were in Lakes Mohave, Mead, and Havasu. By the end of the 1990s, populations in the Green River and Lake Mohave had continued to decline, and it had become necessary to augment these populations with fish raised in hatcheries and other artificial rearing facilities. More complete summaries of distributions of the razorback sucker are presented by Bestgen (1990), Minckley et al. (1991), and the USFWS (2002).

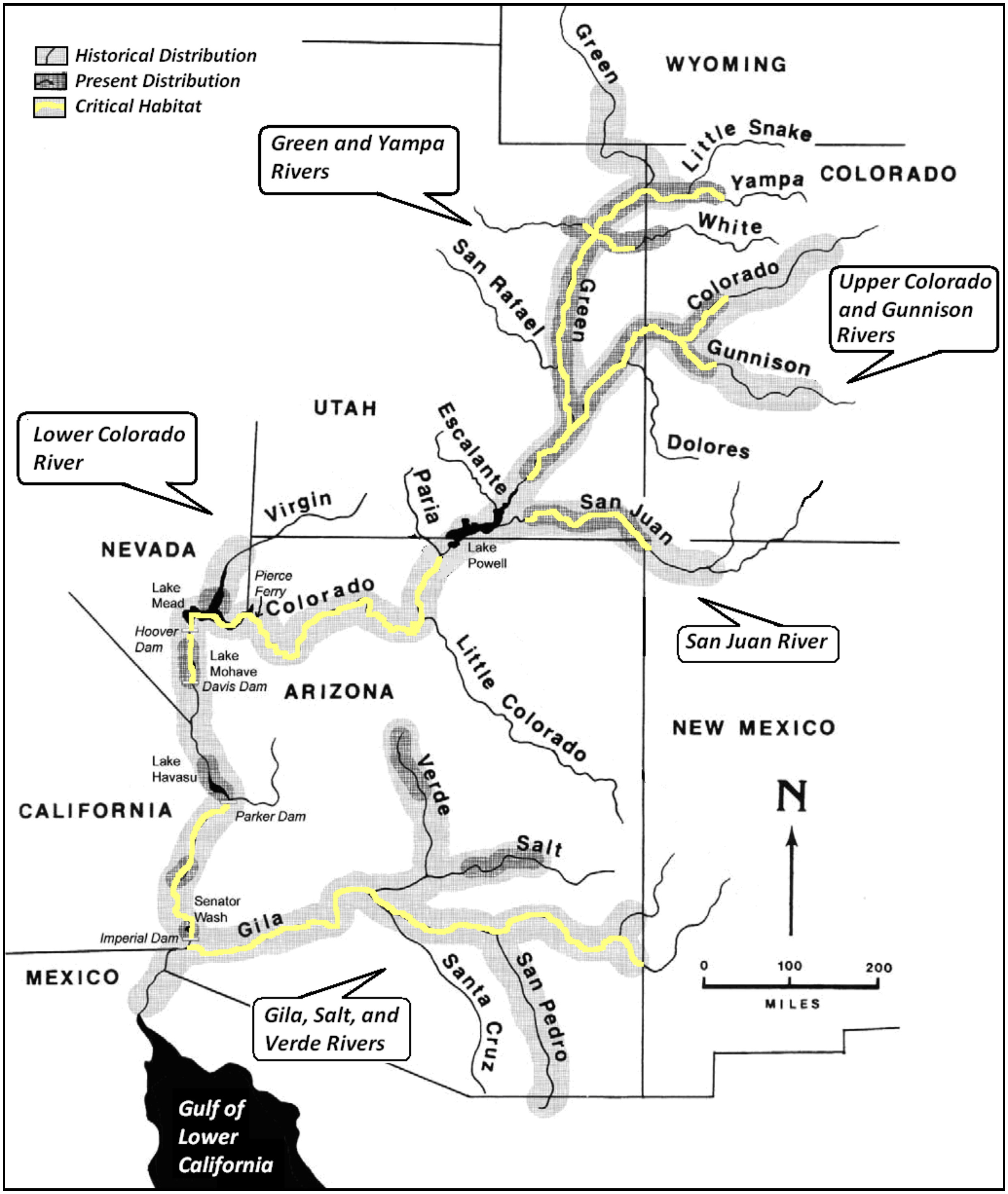

Figure 2. Historical and present distribution of the razorback sucker with designated critical habitat in each of five regions of the Colorado River System. Figure adopted from Maddux et al. (1993) and Schooley and Marsh (2007).

1.5 Present Distribution

For the purpose of this report, the Colorado River System is divided into five geographic regions that are presently occupied by the razorback sucker (Figure 2). These regions are (1) the Green and Yampa rivers; (2) upper Colorado and Gunnison rivers, including Lake Powell; (3) San Juan River; (4) lower Colorado River, including the Grand Canyon, Lakes Mead, Mohave, and Havasu; and (5) the Gila, Salt, and Verde rivers. Each of these regions has unique habitat features that are formed by channel geomorphology and affected by more recent water management systems, especially dams and reservoirs.

There are 1,724 mi (2,776 km) of critical habitat designated for the razorback sucker in the Colorado River System (Figure 2; 50 CFR 13374). A description of each area of critical habitat within the five regions is provided in Table 1. Most areas designated as critical habitat are presently occupied by the razorback sucker, and in some cases, the species is found outside of critical habitat. The numbers of wild fish in these areas are low or non-existent and hatchery fish have been used to reintroduce the species to historical habitat.

In the Green River, a few wild fish remain between the Yampa River confluence and the Colorado River confluence, but most are either stocked fish or progeny of stocked and/or wild fish. Wild fish are gone from the Yampa River and a few fish from the Green River access the lower reaches. Small numbers of fish may be found in the White and Duchesne rivers as individuals moving from the Green River.

Wild fish are extirpated from the upper Colorado and Gunnison rivers, and hatchery fish have been stocked in these rivers for over two decades. Fish passage structures have been retrofitted onto three diversion dams of the upper Colorado River and one on the lower Gunnison River allowing access by the species to historical habitat. Small numbers of larvae are found annually in these rivers indicating some reproductive success.

The wild population is extirpated from the San Juan River, and hatchery fish stocked since 1990 are surviving to adults and have produced larvae annually since 1997. Several diversion structures have been removed or modified to allow passage as far upstream as Farmington, New Mexico. The upstream distribution of the species is limited by cold-water releases from Navajo Dam, and the downstream distribution is the inflow to Lake Powell, where some razorback suckers have been found in recent years.

The razorback sucker in the Lower Colorado River Basin is found primarily in reservoirs, with a few individuals in short intervening reaches of river. The largest self-sustaining population of the species is in Lake Mead and repatriated fish inhabit Lakes Mohave and Havasu. These reservoirs are periodically stocked with hatchery-reared fish. Stocked fish from Lake Havasu have populated the river between the reservoir and Davis Dam, and the fish have spawned and produced larvae in this area starting in the year 2000.

The wild razorback sucker has been extirpated from the Gila and Salt rivers. Small numbers remain in the Verde River, where they are stocked and occupy small reservoirs and intervening river reaches.

Table 1. Distribution and status of the razorback sucker in critical habitat by five regions of the Colorado River System (USFWS 2002).

Region	Critical Habitat (total river miles)	Distribution and Status
Green and Yampa Rivers (421.5 mi)	**Green River:** Yampa River confluence to Colorado River confluence (345 mi)	Largest concentration in upper basin, mainly from Split Mountain to Colorado River confluence; population augmented by hatchery fish.
	Yampa River: Cross Mountain Canyon to Green River confluence (56 mi)	Last reported in 1980s, although 1 fish caught at Lily Park in 2008; some fish access suspected spawning site in lowest reach from Green River.
	White River: Uintah/Ouray Indian Reservation to Green River confluence (18 mi)	Found in low numbers; upstream distribution blocked by Taylor Draw Dam.
	Duchesne River: near Green River confluence (2.5 mi)	Found as small aggregations at mouth during spring runoff.
Upper Colorado and Gunnison Rivers (330 mi)	**Upper Colorado River:** Rifle, Colorado to Lake Powell inflow near North Wash (280 mi)	Wild population extirpated; fish stocked to reestablish population; passage at Grand Valley, Price-Stubb, and Government Highline dams completed; Lake Powell inflow is downstream distribution.
	Gunnison River: Uncompahgre River confluence to Colorado River confluence (50 mi)	Wild fish last found in 1970s; fish stocked in lower 34 mi to reestablish population; Redlands Fishway allows passage since 1996; upstream distribution limited by Hartland Diversion Dam and possibly cold-water releases from Aspinall Unit dams; a few larvae found as evidence of reproduction.
San Juan River (156 mi)	**San Juan River:** Hogback Diversion to Lake Powell inflow at Neskahai Canyon (156 mi)	Wild population extirpated; fish stocked since 1990 are surviving to adults and have produced larvae annually since 1997; diversion structures are being removed or modified to allow passage; Lake Powell inflow is downstream distribution; upstream distribution cold-water releases from Navajo Dam.
Lower Colorado River (432 mi)	**Paria River confluence to Hoover Dam** including Lake Mead at full pool (320 mi)	None reported in Grand Canyon in 20 years; reproducing population in Lake Mead at Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River and Colorado River inflows.
	Hoover Dam to Davis Dam including Lake Mohave at full pool (52 mi)	Stocked fish from Lake Havasu have populated the river between the reservoir and Davis Dam; fish spawned and produced larvae beginning in 2000.
	Parker Dam to Imperial Dam including Imperial Reservoir at full pool (60 mi)	Small numbers reported.
Gila, Salt, and Verde Rivers (385 mi)	**Gila River:** AZ/NM border to Colorado River confluence (300 mi)	None reported in 10 years.
	Salt River: U.S. Highway 60 to Roosevelt Diversion Dam (50 mi)	None stocked since 1996; none reported since 1997.
	Verde River: U.S. Forest Service boundary to Horseshoe Dam including Horseshoe Reservoir at full pool (35 mi)	Small numbers from ongoing stocking.

1.6 General Life History

The razorback sucker is the only species of the genus *Xyrauchen*, but it is related to the lake suckers of the genera *Deltistes* and *Chasmistes*, such as the Lost River sucker (*D. luxatus*), June sucker (*C. liorus*), cui-ui (*C. cujus*), and shortnose sucker (*C. brevirostris*) found in inland lakes of western North America (Miller and Smith 1981; Minckley et al. 1986). The razorback sucker was historically found in main-channel riverine habitats and riverside floodplains, but its apparent evolutionary predisposition to lake environments has enabled it to survive and reproduce in artificial reservoirs created by dams in the last 75 years (Mueller and Marsh 2002).

The life history of the razorback sucker is closely linked to the highly variable conditions of the Colorado River System, especially streamflow and channel geomorphology that differ by river region and have been further modified by human intervention (Figure 3; Bestgen 1990; Muth et al. 2000). In the Green and upper Colorado regions, where some aspects of natural streamflow remain in undammed reaches, adults overwinter in deep pools and migrate to canyons to spawn over clean cobble bars during spring runoff (Table 2). Spawning occurs in May through June, and the eggs incubate 6–7 days in the spaces between cobble/gravel substrate. The larvae emerge and become transported downstream and entrained in floodplains that become inundated during spring runoff and connected to the main river channel. These floodplains are rich, productive nursery habitats where the young feed on plankton, insects, crustaceans, and detritus.

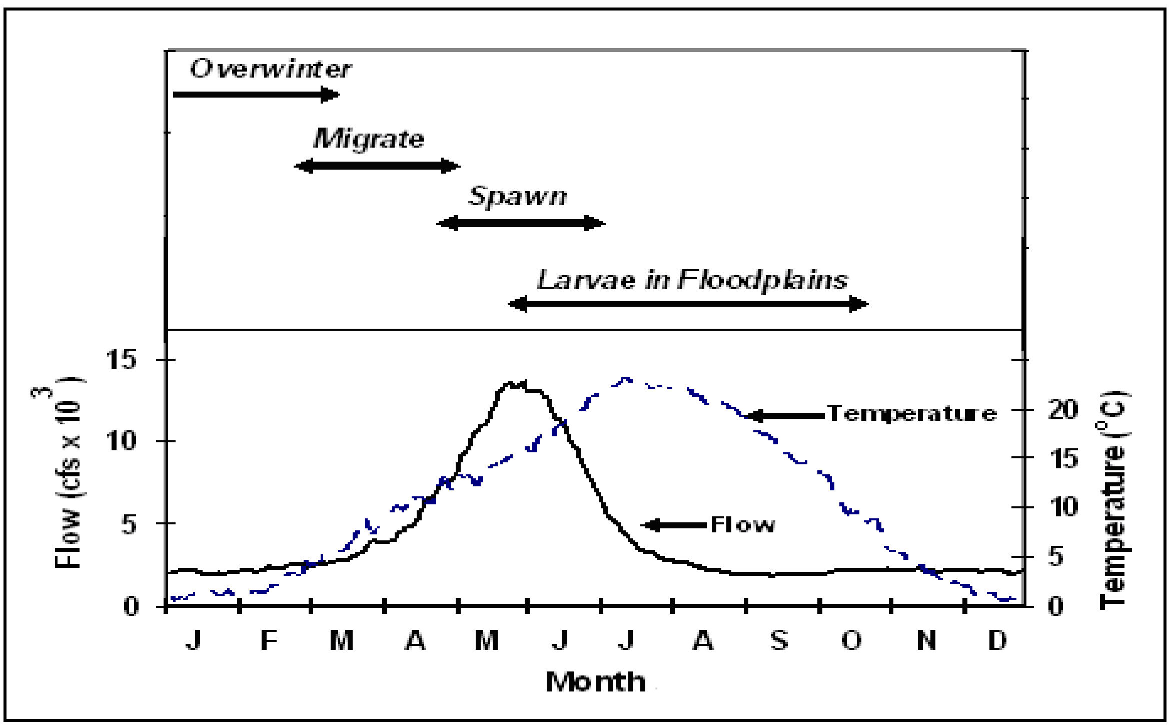

Figure 3. General riverine life history strategy for the razorback sucker, including Overwinter (N-M), Migrate to spawning sites (M-A), Spawn (A-J), and Larvae in Floodplains (M-O). The timing of these strategies is linked to flow and temperature and may vary by river region. Flow is mean of daily mean values for 64 years of record (10-01-1946 – 09-30-2010), and temperature is mean of daily mean values for 8 years of record (10-01-1997 – 09-30-2005), USGS gage near Jensen, Utah.

The timing and chronology of zooplankton development in nursery habitats is vital to the survival of early life stages (Modde et al. 1996). The young return to the main channel with receding river flows or they may become stranded in floodplains until the following year when these are reconnected by the flooding river. The loss or reduction of spring flow peaks together with channelization of the river corridor have reduced the extent of these floodplain nurseries and greatly reduced successful reproduction and recruitment (Muth et al. 2000).

In reservoir environments, adults congregate and spawn in shallow gravel shorelines and emerging young find food and shelter from predators in complex rocky shorelines and vegetation (Kegerries et al. 2009). The numbers of fish predators in these reservoirs is high and in some locations larvae are captured and raised in aquaria and isolated ponds for release back to the reservoir at a larger size (Marsh et al. 2005).

Table 2. Summary of life history strategies and habitat conditions for the razorback sucker in five geographic regions of the Colorado River System.

Region	Spawning	Nursing and Rearing	Juvenile Habitat	Adult Habitat
Green and Yampa rivers	Broadcast eggs on mid-channel cobble/gravel bars near spring runoff in early June.	Larvae drift into newly inundated food-rich floodplains where they remain one to several months.	Young remain in floodplains or occupy main channel backwaters, runs, pools, eddies.	Main channel runs, pools, eddies; may aggregate in connected floodplains or tributary mouths; migrate to spawning bars in spring.
Upper Colorado and Gunnison rivers, including Lake Powell	Broadcast eggs on mid-channel cobble/gravel bars near spring runoff in early June.	Larvae drift into newly inundated food-rich floodplains and gravel pits where they remain one to several months.	Young remain in floodplains or occupy main channel backwaters, runs, pools, eddies.	Main channel runs, pools, eddies; may aggregate in connected floodplains or gravel pits.
San Juan River	Broadcast eggs on mid-channel complex cobble/ gravel islands near spring runoff in early June.	Larvae drift into main channel small backwaters and embayments; some drift into Lake Powell.	Main channel backwaters, runs, pools, eddies.	Main channel runs, pools, eddies.
Lower Colorado River, including Grand Canyon, Lakes Mead, Mohave, and Havasu	Broadcast eggs on rocky lake shores from February to April.	Larvae emerge and remain along shorelines where subject to predation; larvae may be captured and raised in aquaria and ponds.	Use variety of reservoir habitats; few wild juveniles survive because of large predators.	Use variety of reservoir habitats; found mostly in and near bays and inflows.
Gila, Salt, and Verde rivers	Little natural reproduction in small streams.	Larvae may drift into reservoirs where subject to predation.	Pools, runs, eddies of small streams.	Pools, runs, eddies of small streams.

1.7 Relationship of Life Stages to River Geomorphology

The life history and habitat of the razorback sucker in the Colorado River System are closely linked to stream flow and river geomorphology. High spring flows annually stimulate instream production and reshape the channel while cleansing spawning areas of fine sediments. Relatively steady summer and winter flows provide stable, productive environments for all life stages. A history of variable flows has carved deep canyons and shaped the channel geomorphology that provides clean cobble/gravel bars for spawning and productive floodplains for nurseries.

The most striking feature of the Colorado River is its gradient; i.e., drop in elevation from its headwaters in the states of Colorado and Wyoming to its delta in the Gulf of Lower California. The Colorado River has the greatest descent of any river in North America with an average drop of about 7.5 ft per mi (average gradient of 0.0014; Reclamation 1946). It originates at about 15,000 ft elevation and has a length of about 1,500 mi. Below about 5,500 ft elevation, the river is a warm to temperate stream with a channel that varies from reaches confined by steep canyon walls to reaches that are open and meandering. The longitudinal gradient of the river is not continuous, but is characterized by intervening reaches with different channel slopes. In general, low-gradient reaches have sandy substrates and high-gradient reaches have gravel, cobble, and boulder substrates (Schmidt 1996). High to moderate-gradient reaches provide rocky substrate used by the razorback sucker for spawning, while low-gradient reaches often have riverside floodplains used as nurseries during spring runoff. The longitudinal gradient of the river, combined with temperature and productivity, greatly influenced the historical distribution of the razorback sucker in the Colorado River System, but the river continuum has been disrupted by especially the dams and reservoirs of the last 100 years.

The average channel gradient for each reach of the five occupied river regions below about 6,000 ft elevation is presented in Table 3 and illustrated in Figures 4 and 5 (Reclamation 1946). Information is also presented on use by various life stages of the razorback sucker in each reach. This presentation illustrates the importance of channel gradient and substrate to the various life stages of the species in a riverine setting. Generally, spawning takes place in moderate to steep channel gradients, such as in canyon reaches, where cobble/gravel bars are kept relatively clean of fine particles that otherwise may suffocate eggs and embryos. Examples of this spawning activity in higher gradients are spawning bars at the lower end of Split Mountain Canyon and in Desolation Canyon of the Green River; below Palisade on the upper Colorado River; and the middle reach of the San Juan River. Larvae and young nurse and rear in quiet productive floodplains in low-gradient reaches including Jensen to Sand Wash of the Middle Green River; and below Palisade of the upper Colorado River. An exception to this relationship is the use and apparent survival by young razorback suckers in moderate-gradients of the San Juan River.

In the lower Colorado River, where the main channel and tributaries have been fragmented by dams and reservoirs, the razorback sucker is found primarily in lake environments. Wild fish have persisted for about 40 years in major reservoirs of the lower basin, which is equal to about the longevity of the species in the wild. These reservoirs appear to simulate large floodplains used historically by the species, but reproduction and recruitment are dampened by a large suite of predators. Spawning in these reservoirs occurs along open windswept shores over rocky substrates, but emerging larvae and developing young are highly susceptible to predation.

Table 3. Channel gradient of various reaches of the five regions of the Colorado River System and current use by the razorback sucker. Gradients were classified as relatively Low (L<5 ft/mi), Moderate (H=5-8 ft/mi), and High (H>8 ft/mi). This table corresponds to Figures 4 and 5 which illustrate each reach.

River Region	Reach	Gradient[1]	Current Use
Green River[2]	Flaming Gorge Dam to Split Mountain	M-H: 5.2–20.1 ft/mi (0.0010–0.0038)	Little use of lower end and intervening low-gradient parks for residence and over-winter.
	Split Mountain to Sand Wash	L-M: 1.1–4.8 ft/mi (0.0002–0.0009)	High use by all life stages: spawn on cobble/gravel bars, larval drift throughout, entrainment and nursery in productive riverside floodplains that flood in spring.
	Desolation Canyon (Sand Wash to Green River)	H: 9.8 ft/mi (0.0018)	Little use by adults, subadults; suspected spawning on cobble/gravel bars.
	Green River to Colorado River confluence	L: 1.1–2.1 ft/mi (0.0002–0.0004)	Little use by adults, subadults; high use by larvae and age-0; suspected spawning on cobble/gravel bars; little access to riverside floodplains isolated by high berms and channel incising.
Upper Colorado River[3]	Rifle to Palisade	M: 7.7 ft/mi (0.0015)	Moderate use by adults; access from downstream recently restored by fish passage over dams; channel with oxbows and flooded gravel pits as potential nursery areas.
	Palisade to Moab	M: 5.1 ft/mi (0.0010)	High use by adults and larvae in upper areas; suspected spawning on cobble/gravel bars; numerous flooded gravel pits for nurseries; recently augmented with stocked fish.
	Moab to Green River confluence	L: 2.3 ft/mi (0.0004)	Low use by adults; low-gradient sand channel with riverside floodplains isolated by high berms
	Cataract Canyon	H: 10 ft/mi (0.0019)	No use by any life stage reported.
	Lake Powell	--	Low use by adults, subadults, young, especially in San Juan and Colorado River inflows; deep reservoir with steep cliff shorelines reduces potential for spawning as in Lakes Mead, Mohave.
San Juan River[4]	Navajo Dam to Animas River	H: 9.2 ft/mi (0.0017)	No use by any life stage reported.
	Animas River to Bluff	M: 7.4 ft/mi (0.0014)	Moderate-gradient rock channel with some complex reaches used by juveniles and adults year-around and for spawning; population augmented through stocking.
	Bluff to Clay Hills (Lake Powell inflow)	H: 8.3 ft/mi (0.0016)	High-gradient confined rock channel; drifting larvae use backwaters and embayments; some

River Region	Reach	Gradient[1]	Current Use
			drift into Lake Powell inflow.
Lower Colorado River[3]	Grand Canyon (Glen Canyon Dam to Lake Mead inflow)	H: 15.4 ft/mi (0.0029)	High-gradient rocky canyon; few floodplains, some large backwaters; small numbers of adults found.
	Lake Mead	--	Only self-sustaining population left; spawn on cobble shores in bays and inflows; larvae use vegetation to escape predation.
	Lake Mohave	--	Few wild fish remain; program to rehabilitate larvae has helped but number of wild adults continues to decline.
	Lake Havasu	--	Fish stocked in Lake Havasu successfully spawn in river between Davis Dam and Lake Havasu.
	Below Parker Dam	--	Fish stocked below Parker Dam; large numbers of oxbows and floodplains; some restoration; river above delta intermittent.
Gila River[3]	AZ/NM Line to San Carlos Lake	H: 12.4 ft/mi (0.0023)	Fish reported historically; no current use by any life stage reported.
	Coolidge Dam to Salt River	H: 8.7 ft/mi (0.0016)	Fish reported historically; no current use by any life stage reported; river intermittent at times.
	Salt River to Colorado River confluence	L: 3.5 ft/mi (0.0007)	Fish reported historically; no current use by any life stage reported; river intermittent at times.
	Salt River	--	Low survival of stocked fish; few fish remain.
	Verde River	--	Fish stocked annually with some survival in reservoirs.

[1] Channel gradient is measured as the length of the river center in its meander divided by the drop in elevation
[2]Muth et al. (2000)
[3]Reclamation (1946)
[4] Brandenburg and Farrington (2009)

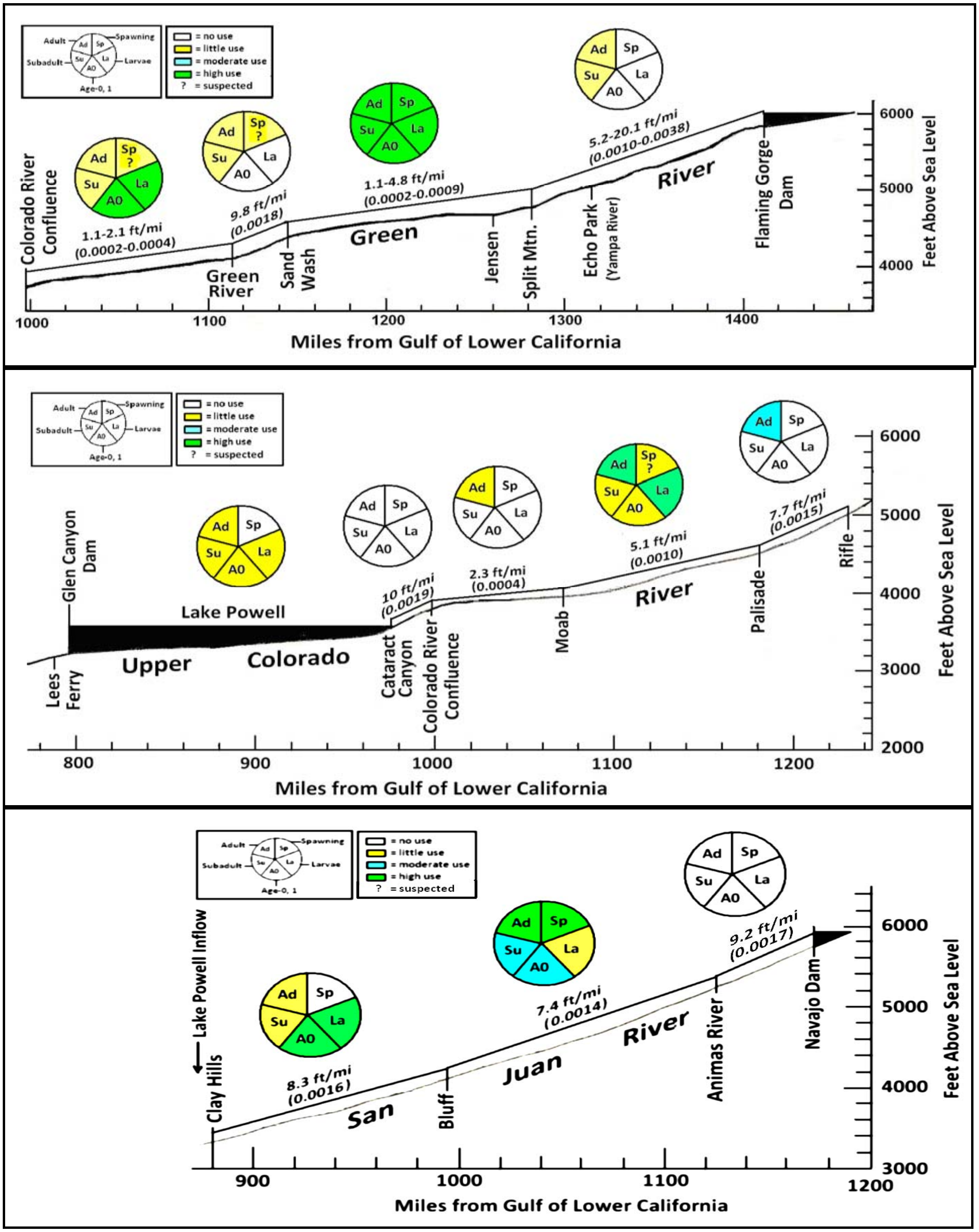

Figure 4. Longitudinal profiles for the Green River, Upper Colorado River, and San Juan River. Average channel gradient by reach is indicated (except for reservoirs), and level of use by life stage of razorback sucker is shown with color-coded pies. See Table 3 for additional information. River profiles and distances from Reclamation (1946) and use by life stage in Green and Upper Colorado rivers from LaGory (2003).

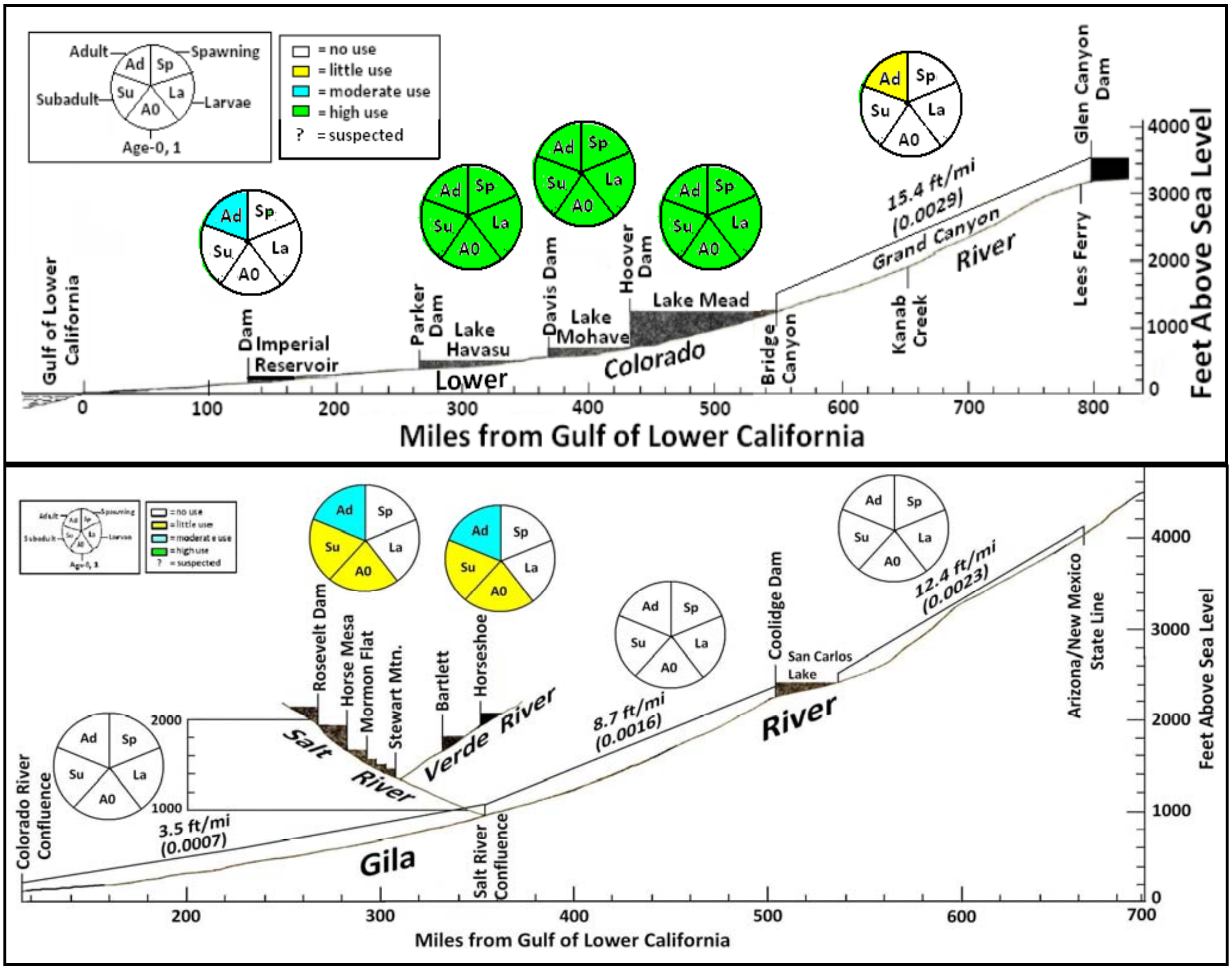

Figure 5. Longitudinal profiles for the Lower Colorado River and Gila River. Average channel gradient for each river reach is indicated (except for reservoirs), and level of use by life stage of razorback sucker for each reach is shown with color-coded pies. See Table 3 for additional information. River profiles and distances from Reclamation (1946).

2.0 HABITAT CHARACTERISTICS AND MANAGEMENT BY RIVER

2.1 Green River

The Green River is the largest tributary of the Colorado River. It originates in western Wyoming and flows south 730 mi to its confluence with the Colorado River in southeastern Utah (Figure 6). The Green River is impounded by Flaming Gorge Dam, about 410 mi upstream from the confluence, and by Fontenelle Dam further upstream. Flaming Gorge Dam strongly affects river flow patterns, sediment load, and water temperature of the Green River. These effects are somewhat moderated by the seasonally variable, sediment-laden, warm waters of the unregulated Yampa River about 65 mi downstream from the dam (Muth et al. 2000).

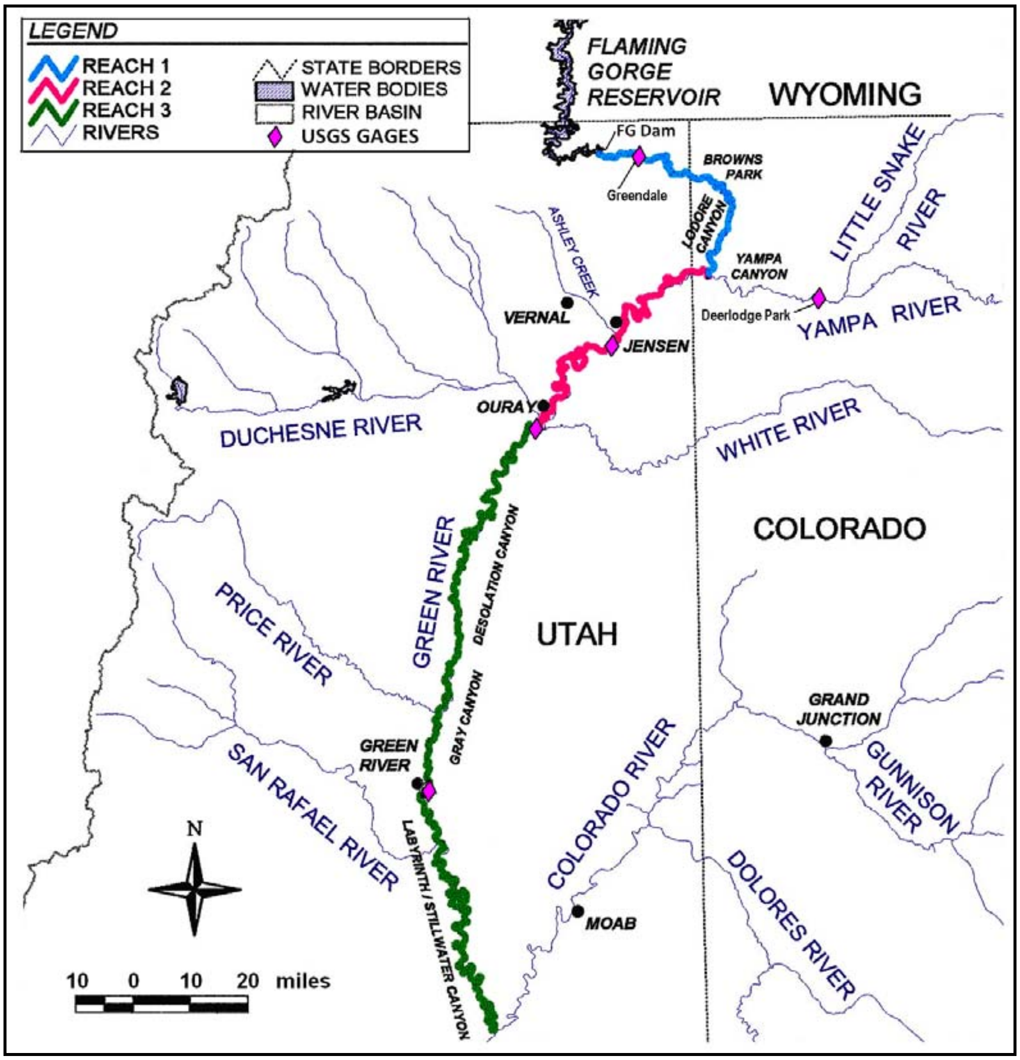

Figure 6. Three reaches of the Green River below Flaming Gorge Dam, Utah. Figure modified from Muth et al. (2000).

The annual hydrographs of the Green River (Figure 7) above the confluence (at Greendale, Utah, in red) and below the confluence (at Jensen, Utah, in purple) are compared with the hydrograph from the Yampa (at Deerlodge Park, Colorado, in blue) and a composite hydrograph combining flows from Greendale and Deerlodge Park (in turquoise). This composite of hydrographs shows that the flow at Jensen, on average, approximates the sum of the flows at Greendale and Deerlodge. The hydrographs also demonstrate the differences between the highly regulated Green River and the unregulated Yampa River. Tributaries further downstream, such as the White, Duchesne, Price, and San Rafael rivers, also help to mitigate the effects of Flaming Gorge Dam. This pattern influences the occurrence of the razorback sucker, which is largely restricted to the portion of the Green River downstream of the Yampa River confluence.

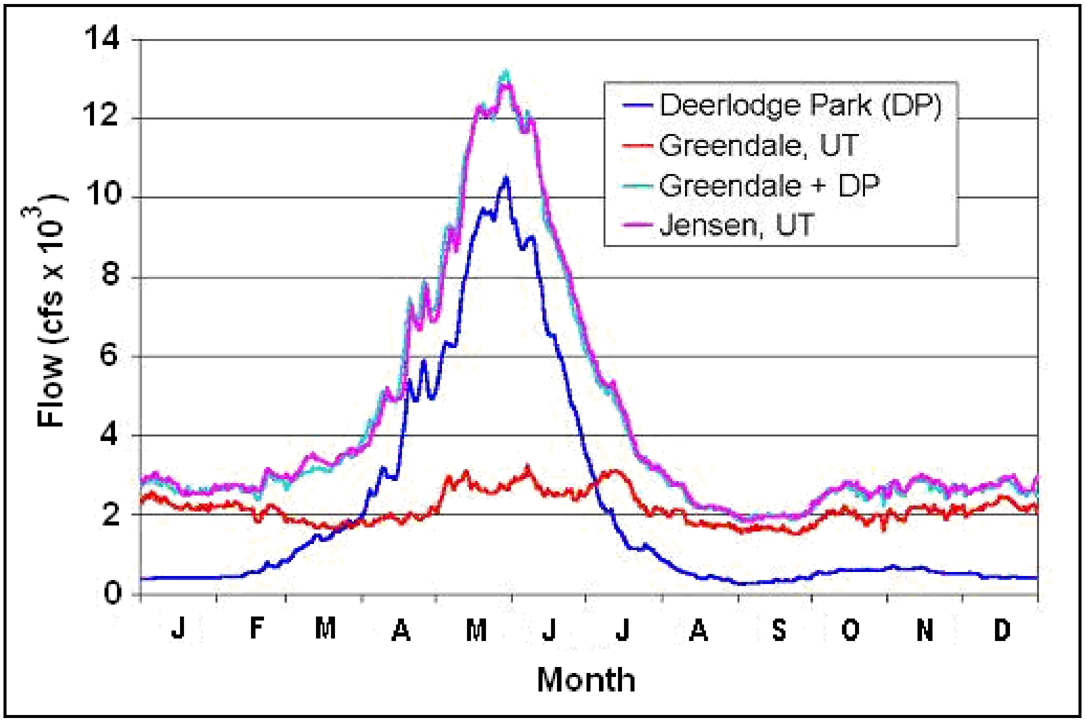

Figure 7. Comparison of annual hydrographs for average daily streamflow of the Yampa River at Deerlodge Park and the Green River at Greendale and Jensen, Utah (1982–1994). Figure from Roehm (2004).

Stream flow characteristics of the Green River below Flaming Gorge Dam were described by Muth et al. (2000) for three major reaches delimited by large tributaries (Figure 6, Table 4). The reach between the dam and the Yampa River has a regulated flow pattern with significant within-day variation, cold water temperatures (4–13ºC) and low sediment load. The middle Green River between the Yampa River and the White River has a more natural flow and sediment regime because of inputs from the Yampa River. The reach includes two canyon segments with a steep gradient, cobble/gravel substrate, and numerous rapids and debris fan-eddy complexes, as well as open parks and a long gentler meandering segment. The lower Green River consists primarily of a low-gradient channel with numerous sandbars and a canyon-bound segment with abundant gravel bars and banks composed of coarse debris-flow material or talus.

Table 4. Stream characteristics of the three major reaches of the Green River below Flaming Gorge Dam. Information from Muth et al. (2000).

Reach		Extent	Description
1. Upper Green River	Flaming Gorge Dam to Yampa River confluence (65 mi)		Straight to meandering channel. Except for Browns Park, channel confined by adjacent steep-walled canyons. Except for minor contributions from tributary streams, flow pattern regulated by Flaming Gorge Dam, with significant within-day variation. Cold water temperatures (4–13ºC) and low sediment load.
2. Middle Green River	Yampa River confluence to White River confluence (99 mi)		More natural flow and sediment regime than Reach 1 because of inputs from the Yampa River, which contributes about 2,000 cfs discharge and 1.9 million tons of sediment. This reach includes four segments:
	Segments	Whirlpool Canyon (11 mi)	Canyon-bound with channel slope of about 0.002. Numerous rapids and debris fan-eddy complexes. Gravel/cobble substrates.
	Segments	Island, Rainbow, and Little Rainbow Parks (7 mi)	Open, with multiple channels and vegetated islands common. Relatively low channel gradient (about 0.0009). Sand substrate.
	Segments	Split Mountain Canyon (7 mi)	Canyon-bound with steeper river gradient (about 0.0038). Boulder/cobble/gravel substrates.
	Segments	Uinta Basin (71 mi)	Predominantly restricted meanders. Gradient from 0.0009 below Split Mountain Canyon to about 0.0003 downstream. Bed materials primarily sand with cobble alluvial fans. Vegetated and unvegetated islands common. Contains inundated floodplains.
3. Lower Green River	White River confluence to Colorado River (245 mi)		The White and Duchesne rivers join the Green River in the Uinta Basin and add about 1,095 cfs discharge and about 4.9 million tons of sediment per year to the mainstem. This reach includes four segments:
	Segments	Uinta Basin (21 mi)	Low gradient (about 0.0002). Numerous sandbars at low flow and prominent low-elevation floodplain areas.
	Segments	Gray and Desolation Canyons (94 mi)	Abundant gravel bars and banks composed of coarse debris-flow material or talus. Prevalent recirculating eddies and regions of stagnant flows. Average channel gradient canyons about 0.001, and bed material ranges from sand in the upper portion and in the recirculating eddies to cobbles and boulders in the riffles and rapids formed by debris fans. The Price River is the largest tributary.
	Segments	Broad Valley (39 mi)	Primarily restricted meanders, with some straight channels. Gradient is about 0.0004. Bed material ranges from sand to gravel and cobble. The San Rafael River is the largest tributary.
	Segments	Labyrinth and Stillwater Canyons (92 mi)	Sinuous river channel with a relatively mild gradient of about 0.0002. Bed material predominantly sand, with numerous emergent sand bars at low flow.

Fish sampling of the Green River began in the late 1960s, and from that period through the 1990s adult razorback suckers were found distributed throughout flat-water sections from the mouth of the Yampa River downstream to the Colorado River, with greatest concentrations generally between the Yampa and Duchesne rivers (e.g., McAda and Wydoski 1980; Tyus 1987; Modde and Wick 1997). This portion of the Green River provides a full complement of suitable riverine habitat, including spawning bars and downstream nurseries in the form of inundated floodplains to support all life stages of the razorback sucker. However, little or no evidence of successful reproduction and recruitment was found, and it was determined that principal causes were disconnection of floodplains from the main channel during all but the highest flows and the presence of large numbers of fish predators in these floodplains.

In 1989, the middle Green River population of adult razorback suckers was estimated at 948 adults (95% confidence interval: 758–1,138; Lanigan and Tyus 1989). Less than 10 years later, Modde et al. (1996) estimated this population at 524 adults, and characterized it as being stable or declining slowly with some evidence of recruitment. They attributed this suspected recruitment to unusually high spring flows during 1983–1986 that inundated portions of the floodplain used as nurseries by young fish. By the year 2000, Bestgen et al. (2002) estimated that the population of wild adult razorback sucker in the middle Green River was only about 100.

Between 1993 and 1999, the abundance of the razorback sucker in the middle Green River dropped to a level comparable to that in the lower Green River (Bestgen and Haines 2010), where only a few larvae and juveniles were captured, indicating probable spawning in the vicinity of the San Rafael River confluence (Gutermuth et al. 1994; Chart et al. 1999; Muth et al. 2000). In the last two decades, augmentation has helped to rebuild population numbers throughout the Green River and stocked fish are being found in spawning areas with wild fish, indicating an incorporation of hatchery fish into the remaining wild stock.

The life history of the razorback sucker in the middle Green River is closely linked to river flow and geomorphology, as is illustrated in Figure 8. Adults migrate in spring to spawn at a cobble/gravel bar below Split Mountain Canyon. The broadcast eggs incubate 6–7 days and emerge as tiny larvae about 0.7 in. long. Following emergence, the larvae are transported downstream by river currents during high flows and become entrained in floodplains (Hedrick et al. 2009). These inundated floodplains are important nursery habitats for larvae and juveniles (Wydoski and Wick 1998; Valdez and Nelson 2004).

Ideally, juvenile razorback suckers would be able to mature in the floodplains for 12 to 24 months before returning to the main channel during high flows (Valdez and Nelson 2004). However, despite the presence of wild larvae in floodplains, few appear to survive to be juveniles and recruitment to the adult population remains low or nonexistent (Modde 1997; Muth et al. 2000; Modde and Fuller 2002; Hedrick et al. 2009). Low survival in these floodplains is attributed to large numbers of nonnative fish that prey upon these larvae (Christopherson et al. 2004). Bestgen et al. (2002) also suggested that negligible recruitment of razorback suckers in the Green River is related to reduced availability of warm, productive floodplain habitat in spring, a mismatch in timing of availability of larvae and inundated floodplains, and the presence of large numbers of nonnative species that prey on the early life stages of the razorback sucker.

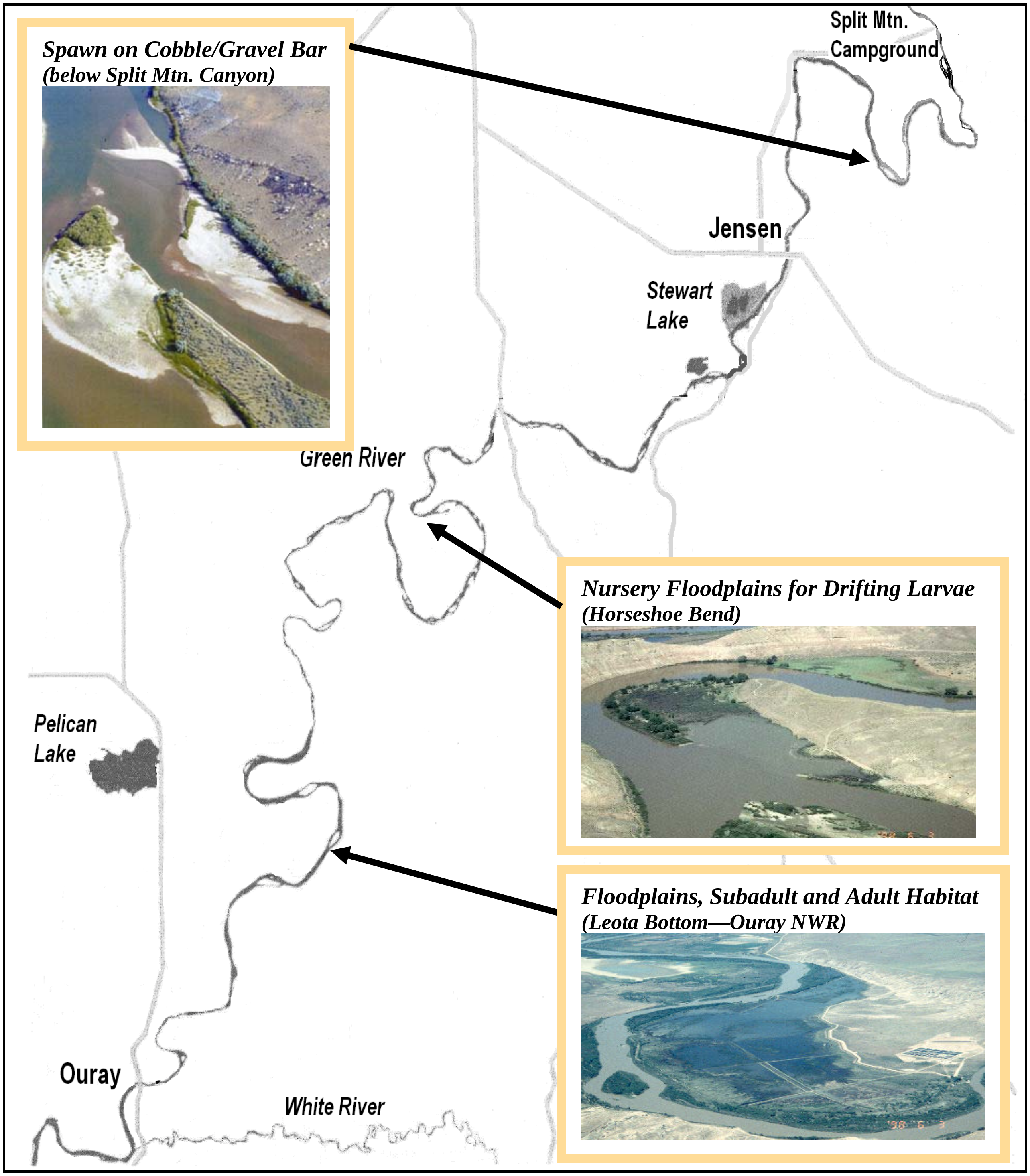

Figure 8. A 71-mi reach of the upper Green River in Utah, from Split Mountain Campground (RM 199) to Ouray (RM 128) with key life history aspects for the razorback sucker, including: spawn on a cobble/gravel bar below Split Mountain Canyon; nursery floodplains for drifting larvae at Horseshoe Bend; and floodplains and subadult and adult habitat near Leota Bottom, Ouray National Wildlife Refuge. Photos courtesy of U.S. Fish and Wildlife Service.

Management efforts on the Green River beginning in 1997 have included breaching levees between the main channel and floodplains to allow entrainment of razorback sucker larvae during high flows (Figure 9; Crowl et al. 2002; Hedrick et al. 2009). Management strategies also involve the draining of some floodplains every few years to kill all nonnative fish and to "reset" floodplain productivity (Valdez and Nelson 2004; Modde and Haines 2005). This strategy appears to be effective as densities of nonnative fish were much lower in reset floodplains than in floodplains with residual fish populations (Modde and Haines 2005). Larval razorback suckers stocked into floodplains that had not been reset had little or no survival (Birchell and Christopherson 2004), but enclosure experiments showed that larvae stocked at densities ranging from 400 to over 4 million per acre could survive and grow at nonnative fish densities found under reset conditions (Christopherson et al. 2004; Brunson and Christopherson 2005).

Another important aspect of allowing floodplains to dry and reset is the large amount of productivity that takes place in these habitats as a principal food source for the larvae. Newly inundated floodplains surge with populations of zooplankton that undergo a chronology of taxa and sizes synchronous with the arrival of developing larvae. Larvae arriving at floodplains have a small terminal mouth that increases in size with growth and eventually becomes subterminal. Zooplankton populations in newly inundated floodplains undergo a chronology of development from small forms such as rotifers, to medium-size copepods, and finally to large cladocerans and bottom-dwelling immature insects. The arrival of drifting larvae and development of their mouth parts must coincide with the development of this zooplankton and benthic community or the young fish will starve (Papoulias and Minckley 1990).

Given the importance of inundated and connected floodplains as nurseries for drifting razorback sucker larvae, the upper Colorado River Endangered Fish Recovery Program has an ongoing agreement with Reclamation to provide a spring-runoff research flow request. A request is made annually for timing and magnitude of releases from Flaming Gorge Dam on the Green River to correspond with high flows from the Yampa River (about 65 mi downstream) in order to maximize flow stage and floodplain inundation. This management action emphasizes the importance of floodplains as nurseries in the Green River.

Adult razorback suckers are known to migrate long distances (>50 mi) to spawn in spring, but they may remain within a localized river reach for the remainder of the year (Tyus and Karp 1990; Modde and Wick 1997). In spring, fish from the lower and middle Green rivers may move upstream for nearly 100 mi to a spawning bar located at the base of Split Mountain Canyon. It appears that hatchery fish are exhibiting movement patterns of wild fish; for example, a hatchery fish stocked in 2004 near the town of Green River, Utah, was captured about 285 mi upstream in the Yampa River near Lily Park in April 2008 (Upper Colorado River Endangered Fish Recovery Program 2009).

Conversely, adult razorback suckers overwintering in the Green River are mostly sedentary, remaining within a 1- to 3-mi reach of river with small, local movements between mesohabitats, each of which may be occupied for several hours at a time (Valdez and Masslich 1989). Flow fluctuations cause razorback suckers to move between habitats, and flow recommendations for Flaming Gorge Dam call for low, steady winter flows to minimize stress to razorback suckers (Muth et al. 2000).

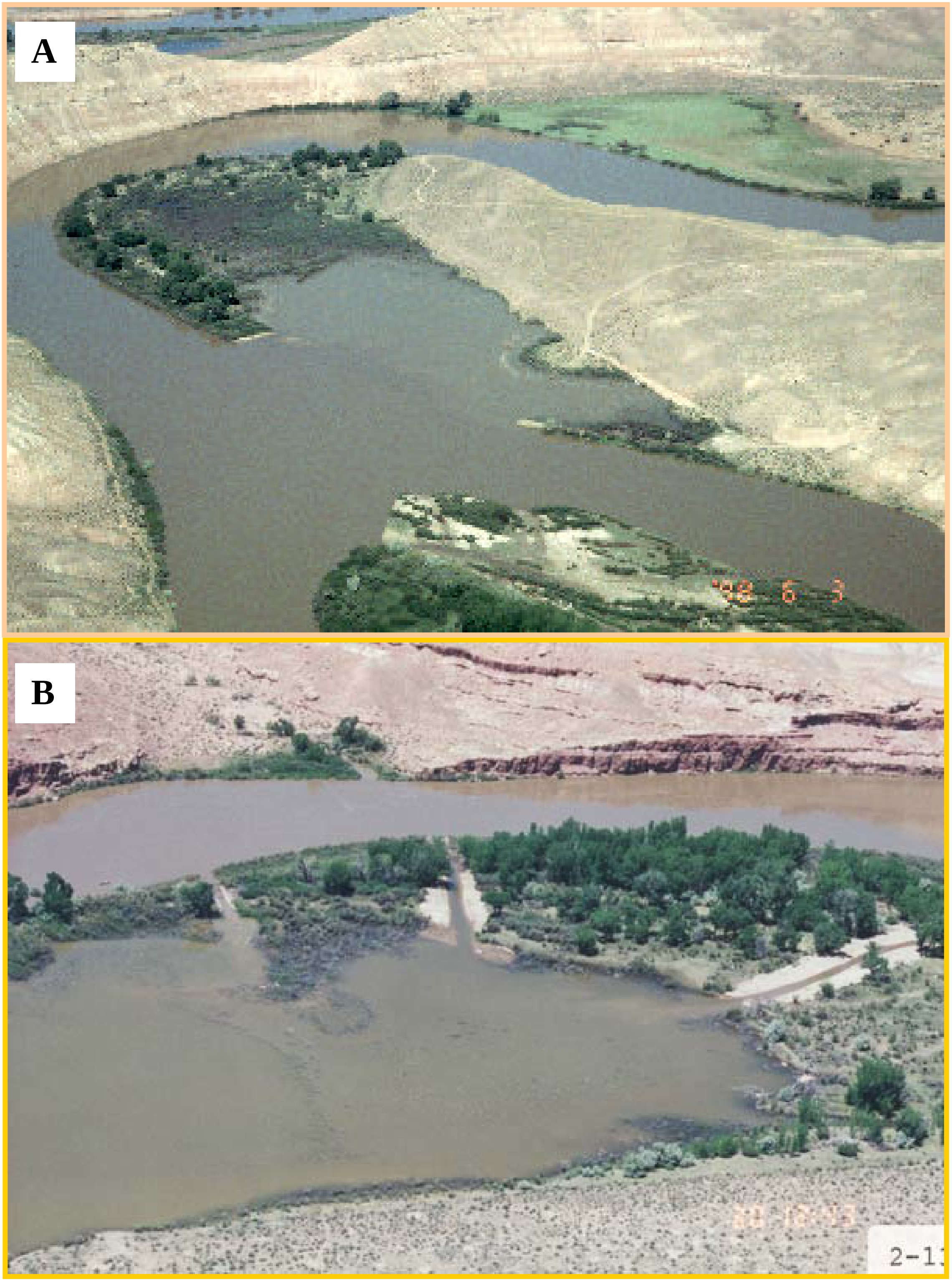

Figure 9. Floodplains of the middle Green River, Utah, managed to entrain drifting razorback sucker larvae at (A) Horseshoe Bend connected with the river through a 1,000 ft wide levee breach, and (B) Brennan Bottom, with three small levee breaches shown as connections between the river channel and the floodplain. Photos courtesy of U.S. Fish and Wildlife Service.

2.2 Yampa River

The Yampa River is the largest tributary of the Green River. It originates in northwestern Colorado and flows approximately 200 mi in a westerly direction to join the Green River in northeastern Utah. Because the Yampa River has not been substantially altered by water-development projects, it still experiences spring peak flows from melting snowpack (see Figure 5), undergoes seasonal temperature patterns, and carries sediment concentrations that resemble historical loads. Spring runoff typically begins as early as mid-March and declines no later than mid-July, with peak flows occurring between April and June (Roehm 2004).

The Yampa River below 6,000 ft elevation comprises both relatively high-gradient canyon reaches dominated by boulder, cobble, and gravel substrates and lower-gradient reaches of meandering canyons and open valleys dominated by finer substrates (Tyus and Karp 1989). Modde et al. (1999) divided the Yampa River between Craig, Colorado, and the confluence with the Green River into eight reaches. The lowest three reaches, from the Little Snake River confluence at Lily Park to the Green River at Echo Park are shown in Figure 10 and briefly described in Table 5. Significant amounts of sediment (2.5 million tons on average) are carried by the river through lower Yampa Canyon each year (O’Brien 1987).

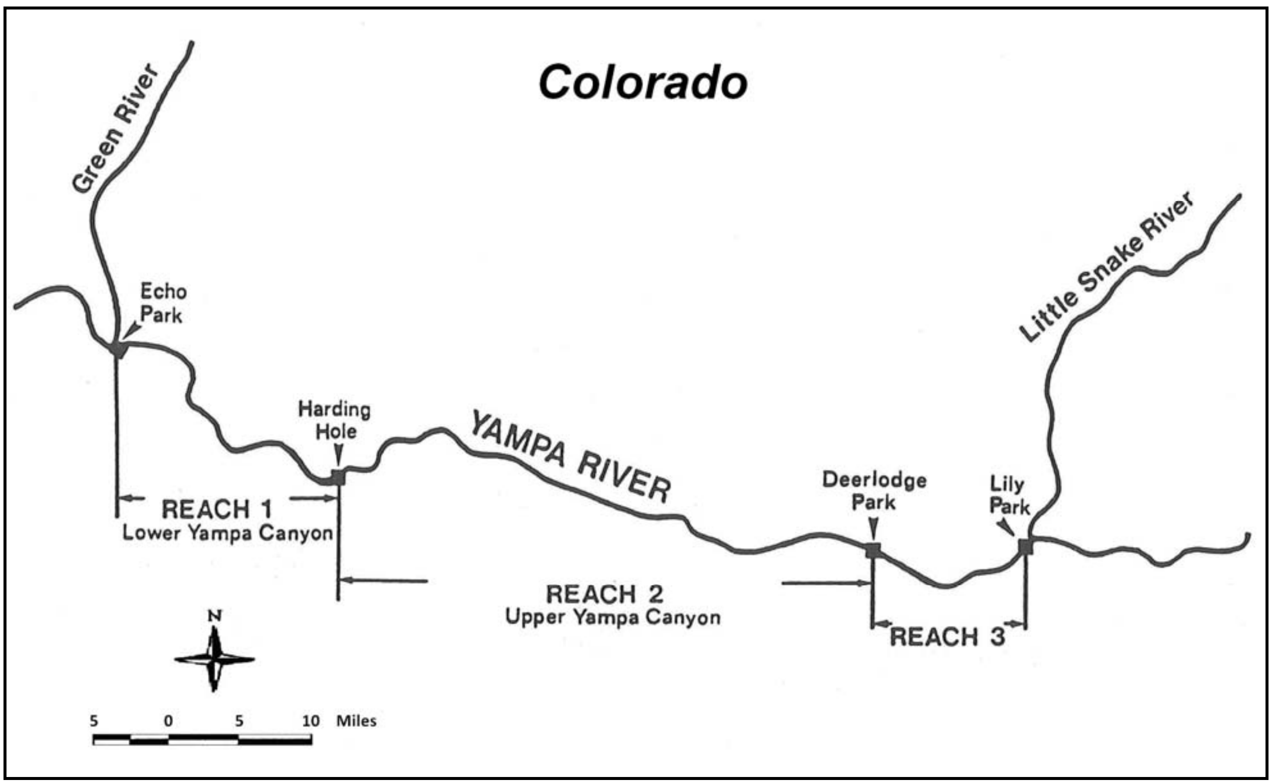

Figure 10. Yampa River reaches from the Green River confluence at Echo Park upstream to the Little Snake River confluence at Lily Park, Colorado. Figure from Muth and Nesler (1993).

Table 5. Yampa River reaches from the Green River confluence at Echo Park upstream to the Little Snake River confluence at Lily Park, Colorado. Information from Modde et al. (1999).

Reach	River Mile	Extent	Description
1	0.0–20.0	Harding Hole to Green River Confluence at Echo Park (20 mi)	A medium-gradient canyon-bound reach, consisting of run, riffle, and pool habitat, with boulder, gravel, and sand substrate.
2	20.0–45.0	Deerlodge Park to Harding Hole (25 mi)	A high-gradient canyon-bound reach, consisting of run, riffle and pool habitat, with boulder and gravel substrate.
3	45.0–51.0	Little Snake River confluence at Lily Park to Deerlodge Park (6 mi)	A low-gradient open-valley reach, consisting of run and riffle habitat, with gravel and sand substrate.

One razorback sucker spawning bar was historically identified about 0.25 mi upstream from the mouth of the Yampa River and another about 1.35 mi further upstream (Seethaler et al. 1979; McAda and Wydoski 1980; Tyus and Karp 1990). The principal spawning bars used today are on the Green River at the southern boundary of Dinosaur National Monument upstream of Jensen, Utah (Tyus and Karp 1990; Hedrick et al. 2009) and upstream of Ouray, Utah (Tyus 1987).

In the Green River, spawning is triggered by a sharply ascending hydrograph and, to a lesser degree, by rising water temperatures (Modde and Wick 1997; Muth et al. 1998). The response of razorback suckers to the rising hydrograph may serve to synchronize spawning activity with floodplain development and food availability (see description of zooplankton and benthic community chronology in section 2.1).

To facilitate spawning activity, flow recommendations for Flaming Gorge Dam call for timing peak releases from the dam to coincide with peak flows from the Yampa River to maximize the spring peak, mimic the natural hydrograph, and inundate riverside nursery floodplains (Muth et al. 2000). Larval razorback sucker are caught annually in the Green River between Jensen and Ouray as evidence of successful reproduction under these flows.

2.3 Upper Colorado River

The upper Colorado River originates in the Rocky Mountains of central Colorado (Figure 11). Its principal tributaries are the Gunnison River and the Dolores River, which originate in San Juan Mountains of southern Colorado. Discharge, streamflow pattern, temperature, and turbidity of these rivers are affected by numerous diversions and dams. The larger storage dams are located some distance upstream from habitat occupied by the razorback sucker and the effect to the hydrograph is primarily a reduction in high spring runoff flows. As with the Green River, this reduction in spring flow has disconnected nursery floodplains from the main river channel. In reaches occupied by the razorback sucker, the annual hydrographs of these rivers are dominated by snowmelt runoff with high flows that usually begin in late April, reach a peak in late May or early June, and wane through July (Pitlick et al. 1999; Figure 12).

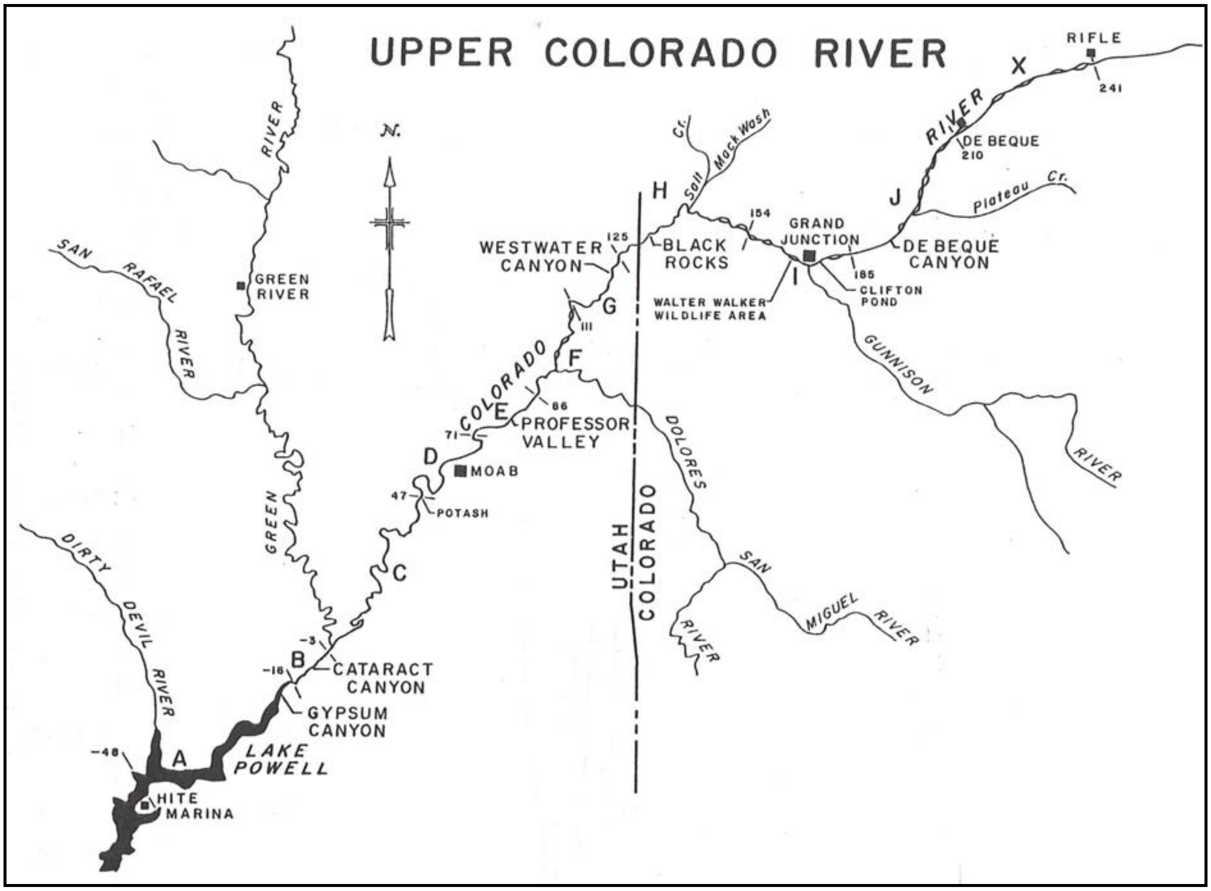

Figure 11. Upper Colorado River from Lake Powell to Debeque, Colorado. Figure from Valdez et al. (1982).

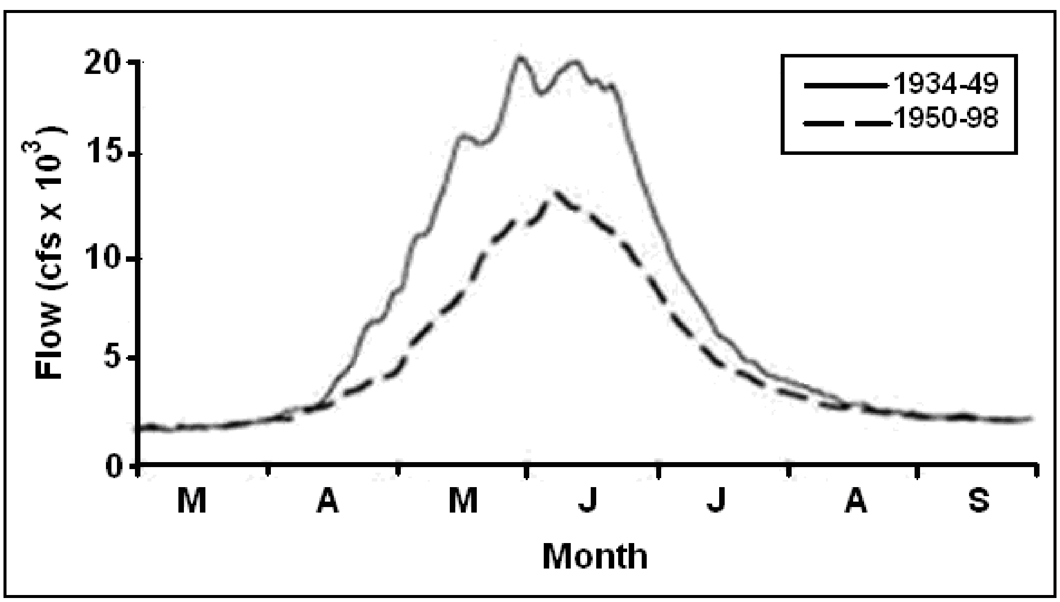

Figure 12. Average daily streamflow of the Colorado River near Cameo (09095550) for the pre-dam period 1934–1949 and for the post-dam period 1950–1998. Figure from Van Steeter and Pitlik (1998).

Formal sampling for razorback suckers in the upper Colorado and Gunnison rivers began in the 1960s (Minckley et al. 1991). Since that time, razorback suckers have been captured in at least 7 of the 11 strata described in Table 6 (Taba et al. 1965; Holden 1973; Valdez et al. 1982; Modde et al. 1995; Osmundson 2001), although the majority of razorback suckers have been captured in the Grand Valley area (Stratum I) (McAda and Wydoski 1980; Valdez et al. 1982; Osmundson and Kaeding 1989a; Osmundson and Seal 2009). This stratum is generally divided into the "15-Mile Reach," which extends upstream from the Gunnison River confluence, and the "18-Mile Reach," which extends downstream from the confluence. An inventory of bottomland (floodplain) habitats along the upper Colorado River showed that the best quality bottomlands were located in the 15-Mile and 18-Mile reaches, as well as near Debeque, Colorado (Irving and Burdick 1995). The 15-Mile and 18-Mile reaches also contain numerous off-channel gravel pits that fill with water during high flows and are often connected to the river.

The numbers of razorback suckers captured in the upper Colorado River decreased dramatically after about 1975. During a 3-year period (1979–1981), Valdez et al. (1982) captured only 52 individuals, all old adults, in a 289-mi reach of the Colorado River from Hite Marina, Utah, to Rifle, Colorado. Between 1984 and 1990, only 12 individuals, including some in reproductive condition, were captured in the Grand Valley, and none were reported anywhere in the upper Colorado River from the mid-1960s to about 1990 (Osmundson and Kaeding 1991).

The last putative wild razorback sucker recorded from the upper Colorado River was captured in 1998 in the 18-Mile Reach (Osmundson and Seal 2009). All razorback suckers captured since then have been stocked fish or (presumably) originated from larvae of stocked fish. While reproduction occurs, no evidence of recruitment in the Upper Colorado River Subbasin has been identified since the 1960s (Burdick 1992; McAda 2003). As in the Green River, the lack of recruitment is thought to be the result of reduced availability of productive, warm-water floodplain habitats and the presence of large numbers of piscivorous nonnative fishes (Burdick 1992).

Radiotelemetry studies in 1986–1988 showed that most razorback suckers in the Grand Valley stratum spent much of the year in the 18-Mile Reach but moved into the 15-Mile Reach in the spring to spawn (Osmundson and Kaeding 1989a). During high spring flows native fish used inundated, off-channel gravel pits, presumably to rest, feed, and stage for reproduction, and spawn. Eighty percent of razorback suckers captured in two gravel pits (Walter Walker Wildlife Area gravel pit in the 18-Mile Reach and Clifton Ponds in the 15-Mile Reach) displayed late stages of sexual maturity, although the predominately silt substrate in the pits did not appear to provide suitable spawning habitat (Valdez et al. 1982).

Razorback suckers and other native fish likely use gravel pits as surrogate habitats for the natural floodplains that were once much more common along the upper Colorado River. However, the predator load in gravel pits is heavy, with nonnative fish occupying the pits year-round, while native fish move in and out of the pits seasonally (Valdez et al. 1982; Burdick et al. 1997; Burdick 2002). Resident populations of nonnative fish in these gravel pits become sources of predators and competitors for mainstem habitats otherwise used by the native fishes.

Table 6. Upper Colorado River strata from Hite Marina at Lake Powell, Utah, upstream to Rifle, Colorado. Table adopted from Valdez et al. (1982).

Stratum	Extent	Stream Characteristics
A	Hite Marina – Rapid 27 (32 mi)	Lake Powell: Canyon-bound with slow current.
B	Rapid 27– Spanish Bottom (13 mi)	Cataract Canyon: Steep canyon walls and talus slopes. Habitat deep, swift runs; many rapids and large eddies; some deep pools and backwaters.
C	Spanish Bottom – Potash (50 mi)	Meandering channel with wide floodplain. Habitat mostly shallow runs with many backwaters. Substrate mostly sand and sand-silt. Banks overgrown with tamarisk. Green River confluence in this reach.
D	Potash – Big Bend (24 mi)	Open valley near Moab. Habitat mainly runs; eddies and backwaters common. Substrate mostly sand-silt. Banks overgrown with tamarisk.
E	Big Bend – Onion Creek (15 mi)	Steep canyon walls with intermittent open valleys. Habitat mostly deep, slow-flowing runs and pools over sand-rock substrate. Few eddies and backwaters.
F	Onion Creek – Agate Wash (25 mi)	Meandering, slow runs and eddies; few backwaters. Substrate mostly rock and sand or rock and sand-silt. Dolores River confluence in this reach.
G	Agate Wash – Westwater (14 mi)	Westwater Canyon: Confined channel; deep runs, eddies and pools. Numerous rapids.
H	Westwater – Loma (29 mi)	Ruby and Horsethief Canyons: Meandering channel through alternating high walls and open parks. Habitat generally runs, some eddies and pools, few backwaters. Substrate generally gravel and rubble with sand-silt deposits. In the Black Rocks segment, channel narrow and deep, with deep eddies, pools and runs, few backwaters.
I	Loma – Palisade (31 mi)	18-Mile Reach and 15-Mile Reach: Meandering channel through Grand Valley, alternating between singlet and multiple channels. Average gradients of 15-Mile and 18-Mile reaches are 0.00175 are 0.0013, respectively. Substrate predominately cobble- and gravel, banks and floodplain mostly fine sand and silt with dense vegetation. Some banks artificially modified by levees and riprap. Numerous vegetated gravel islands and inundated commercial gravel pits. Habitat mostly runs and riffles with some eddies, backwaters, and side channels.
J	Palisade – Debeque (25 mi)	Debeque Canyon: Includes Price-Stubbs Dam, Government Highline Dam (recently fitted with fish passage) Banks rip-rapped with boulders in many places. Habitat mostly swift runs with small pools and eddies, few backwaters. Substrate mostly gravel, rubble, and boulders.
X	Debeque – Rifle(31 mi)	Meandering channel through open valleys and foothills. Habitat shallow- to moderate-depth runs and riffles with numerous pools and eddies. Backwaters uncommon. Substrate mostly gravels, rubble, boulders with some sand-silt deposits.

Management actions and recommendations along the upper Colorado River include restoring floodplain habitats by breaching levees that separate floodplains from the main channel and recontouring off-channel, gravel-pit ponds to promote complete draining during low water and elimination of nonnative fishes (Burdick et al. 1997; Burdick 2002; Valdez and Nelson 2006). In addition to habitat restoration, management actions include augmentation of late summer/fall base flows; spring peak enhancement; fish passage through diversion dams; nonnative fish removal; and propagation and stocking of endangered fishes (USFWS 1999). Between 1999 and 2007, a total of 78,723 juvenile, sub-adult, and adult razorback suckers were stocked in the upper Colorado River, primarily in the 15-Mile and 18-Mile reaches (Osmundson and Seal 2009). Until recently, the Price-Stubb Diversion Dam (11 mi upstream of Palisade, Utah) blocked upstream movement of fish, and the Grand Valley Diversion Dam (8 mi upstream of Palisade) blocked upstream movement of fish seasonally (Osmundson et al. 1995). Both dams have now been equipped with fish passage structures—Grand Valley Diversion Dam in 2005 and Price-Stubb Diversion Dam in 2009—and the species has regained access to historical habitat.

2.4 Gunnison River

The Gunnison River flows approximately 180 mi in a northwesterly direction through Colorado from its headwaters in the San Juan and Elk Mountains to its confluence with the Colorado River at the City of Grand Junction in western Colorado (see Figure 11). Milhous (1995) characterized the lower Gunnison River (below Delta, Colorado, at RM 56) as being a cobble and gravel river, with considerable sand and fine sediment on and amongst the cobbles and gravel. Since 1918, the Redlands Diversion Dam (2.3 mi upstream from the mouth of the river) had blocked upstream movement of fish in the Gunnison River, and in 1996, a fish passageway was installed that allows upstream movement of selected species. Below the Redlands Diversion Dam, the habitat is composed mostly of long, laminar runs, with few side channels and deep pools (Burdick 1997). The average gradient in this reach is about 7 ft/mi. Streamflow of the Gunnison River is affected by upstream dams and diversions, such that spring peak flows have been reduced and summer and winter base flows have been increased (Figure 13).

Above Redlands Diversion Dam to Whitewater (RM 14), the Gunnison River features a wide floodplain with gravel pits; from Whitewater to Bridgeport (RM 29) the river runs through canyon habitat; and from Bridgeport to Delta, the river is braided and bounded by floodplains (Reclamation 2008). Irving and Burdick (1995) identified 48 bottomland sites along the Gunnison River with a total potential area of 3,227 acres. Bottomlands included terraces, depressions, gravel pits, oxbows, side channels, and canyon mouths. The majority of such habitat occurs between Delta and the confluence with Roubideau Creek (RM 50), with the greatest potential for flooded habitat at the Escalante State Wildlife Area (RM 50–52).

In the Gunnison River, razorback suckers were historically abundant near Delta, Colorado. The last two putative wild adults were recorded in 1981 (Holden et al. 1981; Burdick 1992). In an attempt to re-establish the population, approximately 3,000 juveniles and adults were stocked annually in the Gunnison River between 1994 and 2003 (Burdick 2003). Based on captures of larval fish, stocked razorback suckers are reproducing between the Redlands Diversion Dam and Delta, although the spawning location has not been identified (Osmundson and McAda 2007).

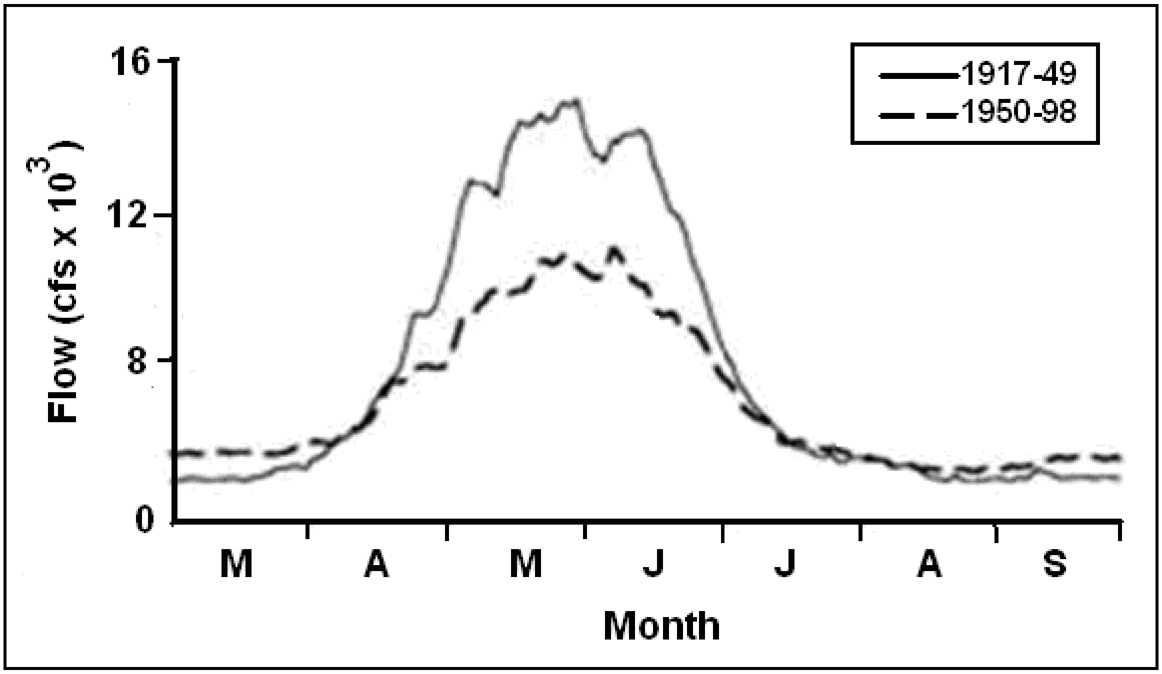

Figure 13. Average daily streamflow of the Gunnison River near Grand Junction (09152500) for the pred-dam period 1917–1949 and the post-dam period 1950–1998. Figure from Van Steeter and Pitlik (1998).

2.5 San Juan River

The San Juan River originates in the San Juan Mountain of southern Colorado. For the 224 mi from Navajo Dam to Lake Powell (Figure 14), mean gradient of the river channel is about 10.1 ft/mi, but it can be as high as 21.2 ft/mi (Brandenburg and Farrington 2009). The San Juan River is narrower, steeper, and shallower than the Green and upper Colorado rivers and lacks the extensive backwaters or flooded bottomlands (Ryden 2000) used in those rivers as nurseries by young razorback suckers. Table 7 provides a brief description of eight geomorphic reaches of the San Juan River between Lake Powell and Navajo Dam (from downstream to upstream) as identified by Holden (1999).

Information on the historical presence of razorback suckers in the San Juan River is limited to a report based on local accounts of razorback suckers ascending the Animas River in spring, presumably to spawn (Jordan 1891) and the testimony of a local fisherman who reported occasionally catching a species, whose description suggests that the fish were razorback suckers, in the San Juan River above Farmington, New Mexico (Koster 1960).

Razorback suckers were not found in 1962 when 100 mi of the San Juan River around the proposed Navajo Dam site was treated with the fish toxicant rotenone (Olson 1962). The only confirmed historical report of the razorback sucker in the San Juan River Basin is two adults seined from a pond near Bluff, Utah, in 1976 (Minckley et al. 1991).

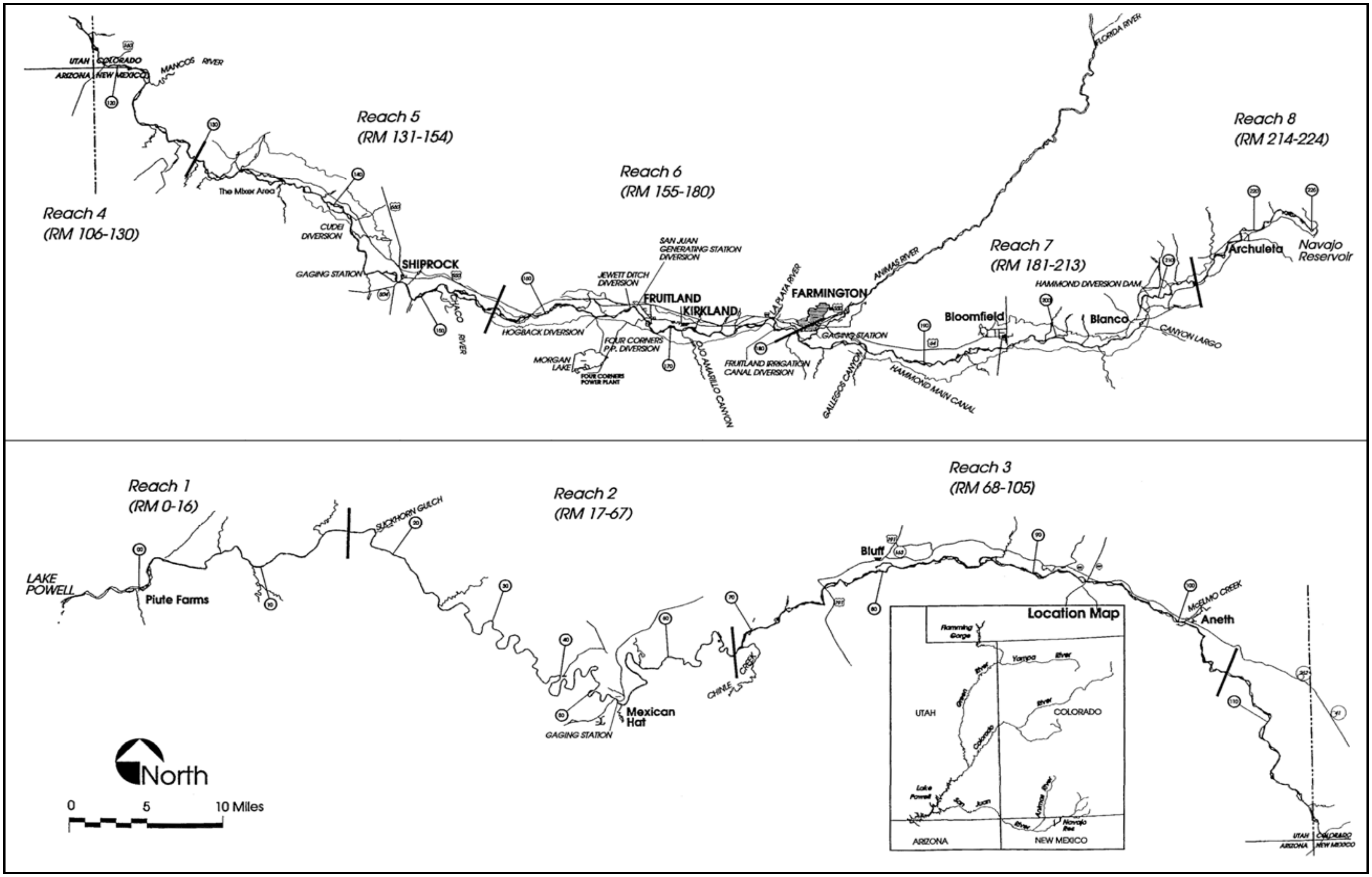

Figure 14. San Juan River from Lake Powell, Utah, to Navajo Dam, New Mexico, showing reaches 1–8 (downstream to upstream). Figure from Holden (1999).

Table 7. Geomorphic reaches of the San Juan River, Lake Powell to Navajo Dam (from downstream to upstream). Information from Bliesner and Lamarra (1999) and Dudley and Platania (2000).

Reach	Extent	Stream Characteristics
1	Lake Powell – near Slickhorn Canyon (16 mi)	Canyon-bound with an active sand bottom. Abundance of ephemeral low-velocity habitat present at certain flows, but greatly influenced by fluctuating Lake Powell levels. Sand and silt deposited to a depth of about 12 m in the lowest end of reach. Lowest-gradient reach in the river.
2	Near Slickhorn Canyon – Chinle Creek confluence (50 mi)	Canyon-bound but upstream of Lake Powell influence. Channel primarily bedrock confined and influenced by debris fans at ephemeral tributary mouths. Riffle habitat dominates, with major rapids. Backwater abundance low, usually in association with debris fans.
3	Chinle Creek to Aneth, Utah (37 mi)	Sinuous channel. Broad floodplain, multiple channels and islands, high percentage of sand substrate. Number of backwater habitats extremely vulnerable to change during storm events. Debris piles common following spring runoff. Low gradient.
4	Aneth, Utah, to below “the Mixer” (123 mi)	Transitional zone between the upper cobble substrate-dominated reaches and the lower sand substrate-dominated reaches. Moderate sinuosity and gradient with some islands. Few backwater habitats.
5	The Mixer to just below Hogback Diversion (23 mi)	Predominantly multi-channeled with the largest total wetted area and greatest secondary channel area of any of the reaches. Cobble and gravel are more common in channel banks than sand. Cudei diversion dam in this reach.
6	Below Hogback Diversion to confluence with the Animas River (125 mi)	Predominately single channel. Cobble and gravel dominant substrate with abundant cobble bars containing clean interstitial spaces. Backwater habitat abundance low. Channel altered by dike construction in several areas. Four diversion dams that may impede fish passage in this reach.
7	Animas River confluence to between Blanco and Archuleta, New Mexico (32 mi)	River channel very stable, primarily embedded cobble substrate as a result of Navajo Dam upstream. Much of the bank stabilized and/or diked. Water temperature influenced by hypolimnetic releases from Navajo Dam.
8	Between Blanco and Archuleta and Navajo Dam (11 mi)	Tailwaters of Navajo Dam. Primarily single channel, with 4–8 secondary channels. Cobble dominant substrate. Cool, clear water conditions.

River-wide electrofishing surveys of the San Juan River in 1987–1989 from Farmington to Lake Powell yielded only one ripe male razorback sucker near Bluff, Utah, and 16 ripe adults at Piute Farms in the San Juan arm of Lake Powell (Platania et al. 1991). Subsequent surveys in 1991–1997 failed to yield any wild razorback suckers of any life stage from the main channel of the San Juan River (Ryden 2000).

Hatchery-raised razorback suckers were stocked into the San Juan River beginning in 1994, and the population in the river is currently maintained by stocking hatchery fish. Spawning activity by razorback suckers was detected in the San Juan River in 1997, and an intensive monitoring program for larvae was initiated in 1998, when two larval razorback suckers were collected (Ryden 2000). Annual monitoring for small-bodied and larval fish from 1998 to 2008 has resulted in the capture each year of larval razorback suckers (Brandenburg and Farrington 2009). Although young-of-year were not detected during fall sampling, individual age-1 razorback suckers were collected in 2004 and 2006 (Paroz et al. 2009). The lower San Juan River provides little nursery habitat, and razorback sucker larvae that drift downstream into Lake Powell may not survive because of predation by large numbers of nonnative fish (Marsh and Minckley 1989; Minckley et al. 1991; Mueller et al. 2001).

Notably, because of its steep gradient, the San Juan River lacks the large riverside floodplains used as nurseries by young razorback suckers in the middle Green River and the upper Colorado River. Nevertheless, the San Juan River channel is complex is some locations and small-bodied fishes use backwaters and embayments along shorelines as nursery habitats. Research in the San Juan River continues to determine if larval razorback suckers can survive and recruit by using alternative nursery areas, other than inundated floodplains (SJRIP 2009).

Management actions identified in a Long-Range Plan (SJRIP 2009) are designed to benefit the razorback sucker and other native fish in the San Juan River, and include operation of Navajo Dam in a manner that mimics the natural hydrograph, restoration of backwater and side channel habitats, construction of fish passages and screens at diversion structures, nonnative fish removal, off-site propagation, augmentation, and monitoring. A total of 58,916 razorback suckers were stocked into the San Juan River in the period 1994–2008, with 46,073 (78%) of these stocked from 2006 to 2008 (Furr and Davis 2009; see also Valdez et al. 2012).

Beginning in 1992, Navajo Dam has been operated to mimic a natural San Juan River hydrograph (Holden 1999), with the magnitude of the high spring release linked to the amount of precipitation recorded during the preceding winter (Dudley and Platania 2000). As an example, Figure 15 shows the hydrograph for the San Juan River at three gauging stations in Water Year 1999.

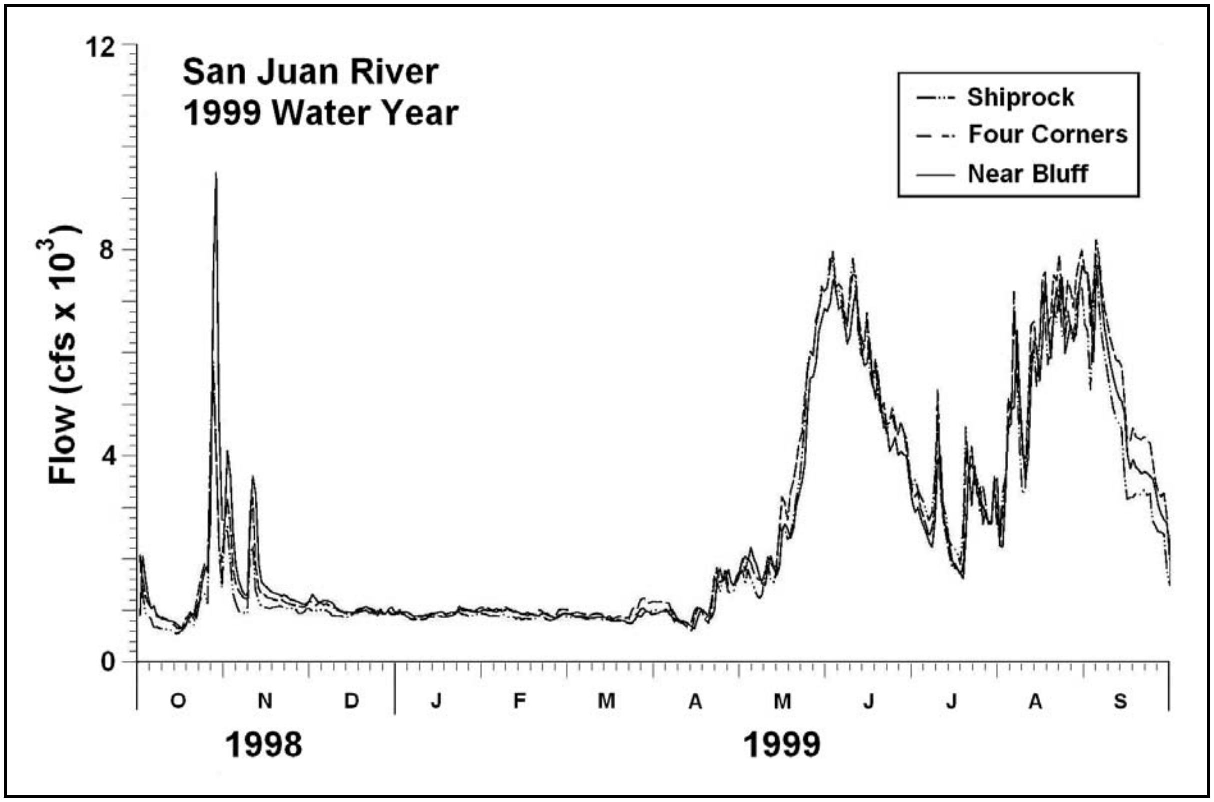

Figure 15. Average daily treamflow of the San Juan River at Shiprock, NM; Four Corners, CO; and Bluff, UT, for Water Year 1999 (October to October). Figure modified from Dudley and Platania (2000).

2.6 Lower Colorado River and Reservoirs

The lower Colorado River, as defined here, extends approximately 800 mi from Glen Canyon Dam to the river's outflow in the Gulf of Lower California (Figure 16). It is a highly regulated river with three large water storage reservoirs (Lakes Mead, Mohave, and Havasu) and several smaller reservoirs and water diversion structures. Portions of the river not impounded by dams have been heavily dredged, channelized, and confined by levees, and river banks are often rip-rapped. Major habitat types in the lower Colorado River include reservoirs, inter-reservoir river segments, and natural and modified backwaters. Backwater types include oxbow lakes, abandoned river channel pools, off-channel ponds and lakes, secondary river channel pools, and hydrologically isolated coves on reservoirs (Saiki et al. 1980; LCRMSCP 2004).

Hoover Dam, Davis Dam, and Parker Dam impound the waters of the lower Colorado River in Lake Mead, Lake Mohave, and Lake Havasu, respectively. Lake Mead, as the oldest reservoir (1935), is a mesotrophic lake (i.e., intermediate in nutrient levels and productivity); Lake Mohave, as the youngest reservoir (1951), is clear but highly productive; and Lake Havasu (1938) is a relatively shallow, mesoeutrophic (i.e., tending toward high nutrient levels and high primary productivity), warm-water lake (LCRMSCP 2004).

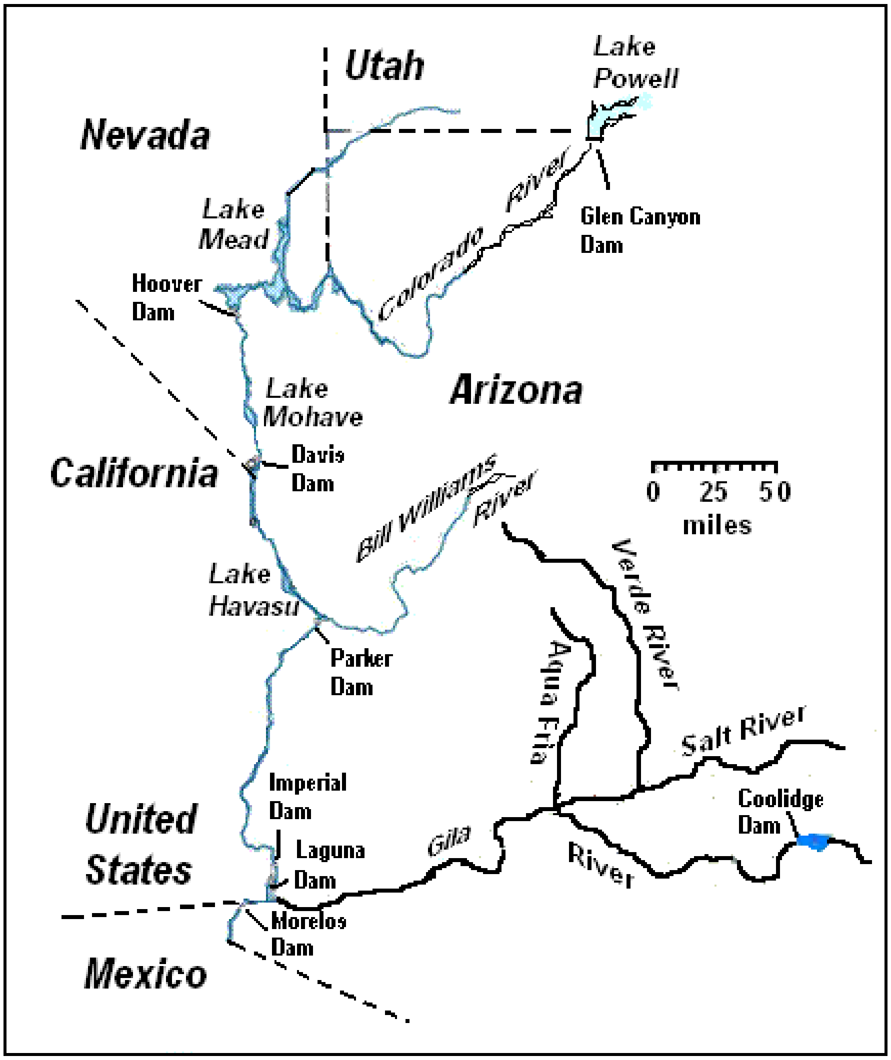

Figure 16. Lower Colorado River from Lake Mead to the U.S.-Mexico border.

All three reservoirs feature complex and irregular shorelines with numerous coves formed by topographic relief. All have shallow, warm littoral zones with shoals of cobble, gravel, and sand (Minckley 1983; Bozek et al. 1991; LCRMSCP 2004; Wydoski and Mueller 2006). Shorelines and littoral habitat vary with reservoir water levels that fluctuate on an annual basis as dam operations respond to inflow volumes and downstream water demands.

Since 1999, drought conditions in the Southwest have resulted in a major drawdown of Lake Mead and major changes in shoreline morphology as the water level recedes. Water in the reservoirs is generally clear, but at shallow inflow areas, sediment-laden rivers (e.g., Colorado, Muddy, and Virgin rivers) generate turbidity plumes. The low-angle shoreline topography of these reservoirs is quite in contrast to the high-angle, canyon-bound shoreline of Lake Powell, which is formed within the largely confined vertical cliffs of Glen Canyon; these vertical cliffs minimize opportunities for shoreline spawning fish.

Razorback suckers occur in small numbers in all major habitat types along the lower Colorado River (reservoirs, inter-reservoir mainstream segments, and natural and artificial backwaters). Through 2004, approximately 2.4 million razorback suckers were repatriated into the lower Colorado River mainstem; 507,123 into Lake Havasu; 121,668 into Lake Mohave; and 146 into Lake Mead (Albrecht et al. 2009). Repatriation is the process whereby recently hatched larvae are captured and raised in artificial environments, then held in sheltered coves before releasing them back to the reservoir after they are sufficiently large to avoid most predators. The program has had some success, but survival of stocked razorback suckers has been low, most likely due to predation by large nonnative species, such as striped bass (Minckley et al. 2003; Mueller 2006). Nevertheless, this repatriation program has helped to extend the life of the population in especially Lake Mohave (Marsh et al. 2003).

The razorback sucker's unusual ability to spawn in both flowing and standing water (Mueller 2006) is demonstrated in the lower Colorado River corridor, where spawning has been documented in Lakes Mead and Mohave; in the mainstem river between Davis Dam and Lake Havasu; in Senator Wash Reservoir; and in Cibola High Levee Pond, an off-channel pond below Parker Dam (Wydoski and Mueller 2006; Mueller 2007; Albrecht et al. 2008b). Recruitment is limited but has been documented in the lower Colorado River corridor in Lake Mead (Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River and Colorado River inflow areas); Lake Mohave (Yuma and Davis Coves); and in Cibola High Levee Pond in the Cibola National Wildlife Refuge below Parker Dam (Mueller 2007, Albrecht et al. 2008b). Yuma and Davis Coves and Cibola High Levee Pond are semi-natural areas managed as off-channel "sanctuaries" for native fish (Mueller 2006). Recruitment also occurred outside the lower Colorado River valley in a population of razorback suckers stocked into Rock Tank, an isolated stock tank in Buenos Aires National Wildlife Refuge in southeastern Arizona. The fish were removed in 1997 after being observed gasping for oxygen at the surface of the tank (Bonar et al. 2002).

The life history of the razorback sucker in reservoirs of the lower Colorado River is similar to that seen in riverine environments, but is manifest differently because of available habitats, an earlier seasonal warming pattern with the more southern location of the lower basin, and management actions that help the young fish survive. Reservoirs in the lower basin warm earlier than rivers of the upper basin, and razorback suckers spawn in February-April on shorelines with cobble and large gravels. Because of the large numbers of fish predators in these reservoirs, larvae are captured at emergence and raised in small aquaria then placed in isolated coves or ponds that serve as sanctuaries from predators. Such isolated coves include Yuma Cove on the shoreline of Lake Mohave and Office Cove on the shoreline of Lake Havasu (Figure 17). The fish are generally held in these sanctuaries until they reach 300–400 mm TL, which is a size no longer susceptible to predators. The fish are then released back into the reservoir. This strategy of repatriation is described more fully in Marsh et al. (2005) and Mueller (2006, 2007).

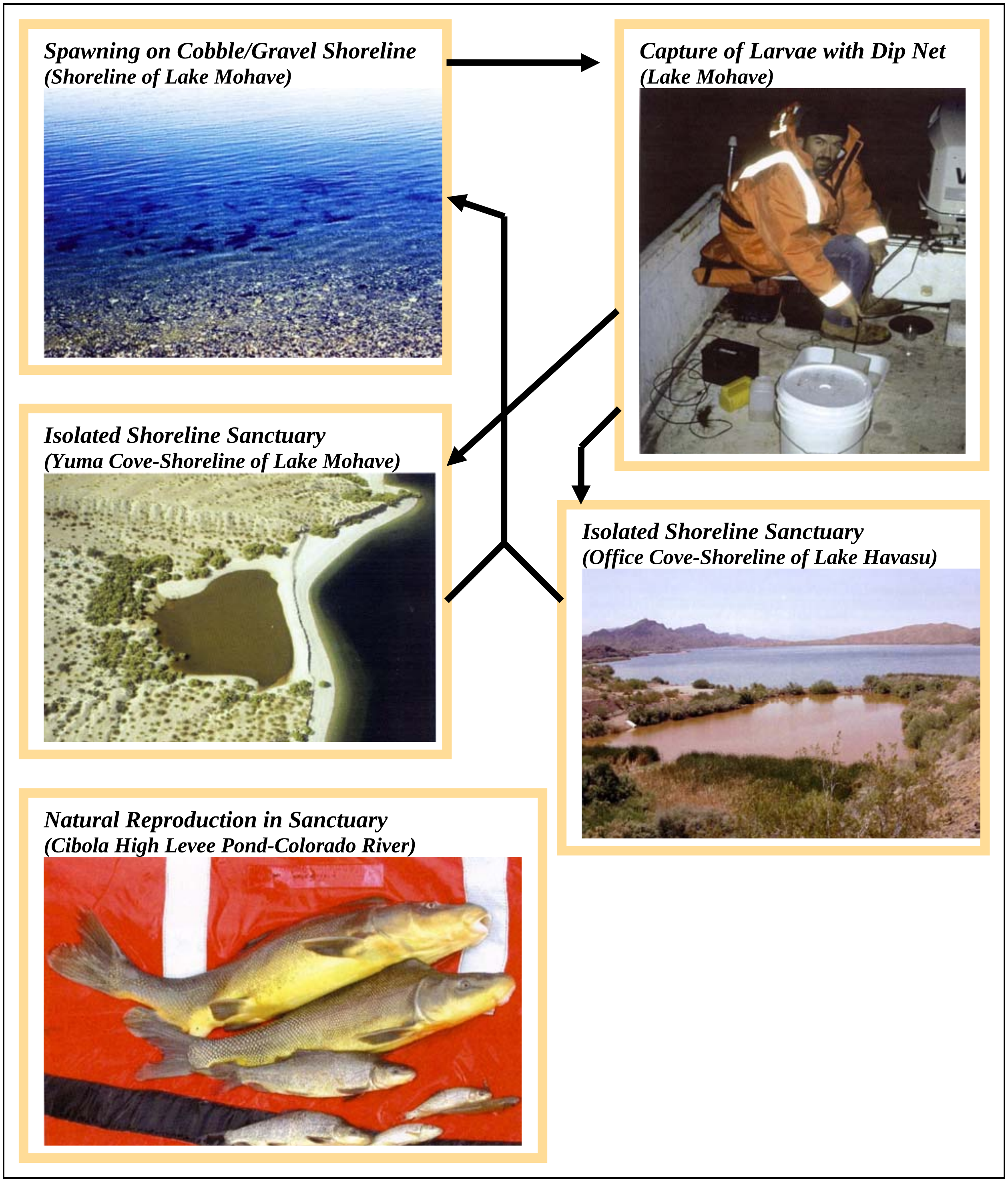

Figure 17. Key life history aspects for the razorback sucker in reservoirs of the Lower Colorado River Basin, including spawning on a cobble/gravel shoreline of Lake Mohave; capture of larvae; rearing of larvae and juveniles in sanctuary coves of Lake Mohave and Lake Havasu, and in sanctuary ponds of the Colorado River; and the result of natural reproduction in the Cibola High Levee Pond. Photos from Mueller (2006, 2007).

2.7 Gila, Salt, and Verde Rivers

The Gila River is the major tributary of the lower Colorado River (Figure 16). It originates in the mountains of western New Mexico and flows in a westerly direction into Arizona. The major tributaries of the Gila River are the Salt, Verde, and Aqua Fria rivers, which originate in north-central Arizona. The Gila River has a highly variable flow, as indicated by the stream gauge near Red Rock, New Mexico (Figure 18). Through regions of the Gila River, historic flows may have exceeded 10,000 cfs—or the channel may have dried at times. Water diversions and dams have moderated, but also exacerbated this flow variability and the lower portions of the Gila River often dry in summer.

The razorback sucker was once abundant and widely distributed throughout the Gila River Basin in Arizona, including all major tributaries except the Santa Cruz River; however, wild razorback suckers are now extirpated from the drainage (Desert Fishes Team 2003, 2006). In a massive effort to re-establish the species, more than 12 million razorback suckers were stocked in the Gila, Salt, and Verde rivers and several tributaries between 1981 and 1991 (Hendrickson 1993). This effort was considered largely unsuccessful, primarily because of predation by nonnative, fish such as flathead catfish (*Pylodictus olivaris*; Marsh and Brooks 1989). The fish were variously stocked throughout the system and 14 adults were later reported from Fossil Creek, a small tributary of the Verde River.

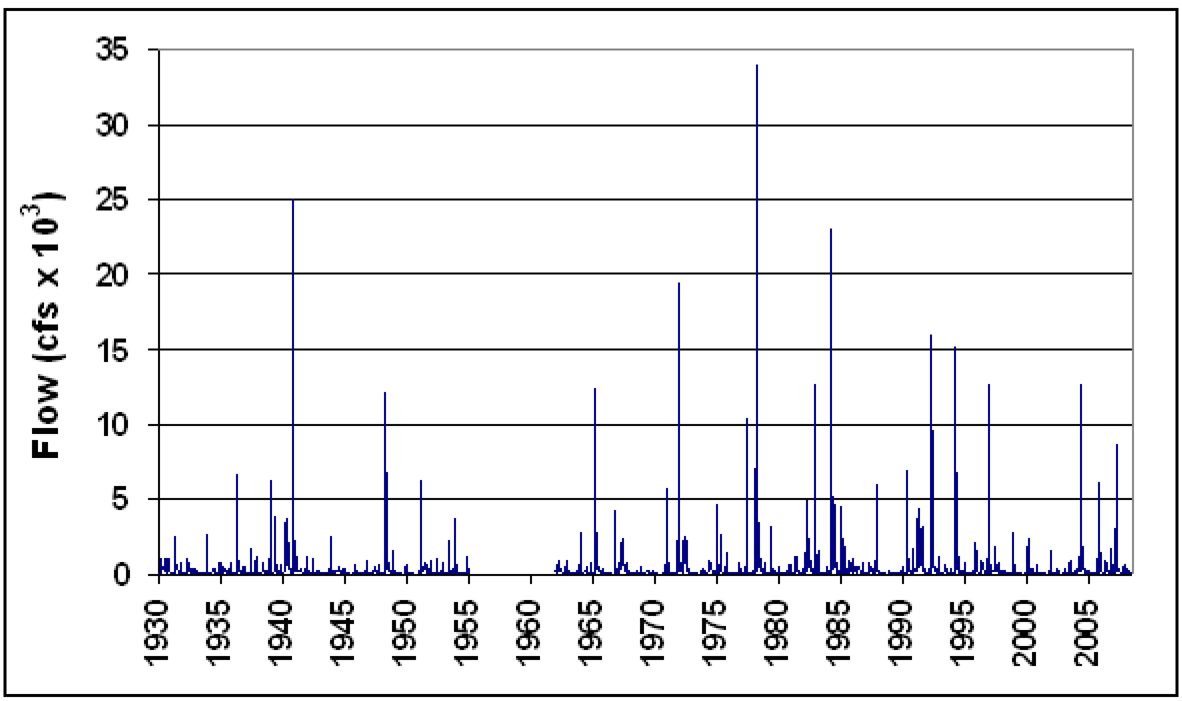

Figure 18. Average daily streamflow of the Gila River near Red Rock, NM, 1930–2005; USGS stream gauge 09431500.

Beginning in 1991 and extending through 2003, close to 23,000 larger razorback suckers (>300 mm TL) were stocked into the Verde River, and in 1996 approximately 2,000 were stocked into the Salt River (Hyatt 2004). Razorback suckers continue to be stocked in the Verde River, but none have been stocked in the Salt River since 1996. Despite intensive monitoring, none have been recaptured since a single fish was caught in 1997. Both rivers appear to provide suitable habitat for the species, including heterogeneous streams with both canyon-bound and open reaches, stretches of fast and slow current, and areas of coarse (gravel/cobble) and fine (silt/sand) sediment substrates. Nonetheless, few stocked fish are known to have survived longer than a few months after repatriation, and there is no evidence of recruitment. Most razorback suckers captured were at or near stocking sites (Hyatt 2004).

The Arizona Game and Fish Department (AGFD) stocks razorback suckers in the Verde River as mitigation for the operation of Bartlett and Horseshoe reservoirs. A Habitat Conservation Plan (HCP) in 2010 includes provisions for expanding the Page Springs Bubbling Pond Fish Hatchery, the only warm water hatchery in Arizona. The hatchery currently raises about 12,000 endangered razorback suckers annually for replenishment in the Colorado River, and will expand the facility to release more fish into the Verde River. As part of the HCP, the Salt River Project (SRP) has agreed to construct a fish barrier at Lime Creek to prevent nonnative fish from traveling upstream and threatening the native species.

3.0 MESOHABITAT USE BY LIFE STAGE

Sections 1.0 and 2.0 of this report have described the historical and present distribution of the razorback sucker, and the habitat characteristics by each of the major regions and rivers. These sections have provided the setting for the historical and present conditions used by the species in the Colorado River Basin. The following Sections 3.0 and 4.0 describe the more localized mesohabitat and microhabitat used by various life stages of the species.

The term mesohabitat is used in this report to describe major local physical features used by the razorback sucker. In rivers, mesohabitats include pools, eddies, runs, cobble and gravel bars, backwaters, inundated floodplains, oxbows, and gravel pits. In reservoirs, mesohabitats include shallow cobble and gravel shoals, shorelines, coves, turbid inflow areas, and deep pelagic zones. Razorback suckers are also known to occupy small streams, irrigation canals, ponds, and stock tanks (Ulmer et al. 1985; Marsh and Minckley 1989; Bonar et al. 2002). A summary of mesohabitats used by various life stages is provided in Table 8, and the following sections describe habitat use in detail.

3.1 Spawning

The razorback sucker is a broadcast spawner that releases and fertilizes its semi-adhesive eggs near the river bottom so that incubation can take place in protected interstitial spaces of cobble and gravel substrates. In the Upper Colorado River Basin, razorback suckers spawn in rivers during spring runoff (mostly April–June) in association with the ascending and peak hydrograph (Tyus and Karp 1989, 1990, 1991; Bestgen 1990; Osmundson and Kaeding 1991). Muth et al. (1998) reported that spawning activity spanned 4–6 weeks each year, with the exact timing varying annually with changing flow conditions. During spawning, adults congregated in runs, backwaters (flooded bottomlands and gravel pits), and impounded tributary mouths near spawning sites (Holden and Crist 1981; Valdez and Wick 1983; Tyus 1987; Osmundson and Kaeding 1989a; Tyus and Karp 1990; Osmundson et al. 1995; Modde and Wick 1997; Modde and Irving 1998). In the Green and Yampa rivers, these spawning sites included bars of cobble, gravel, and sand in the main channel and alluvial deposits at confluences (McAda and Wydoski 1980; Tyus 1987; Tyus and Karp 1990).

Spawning has also been documented or suspected in off-channel habitats. In the upper Colorado River near Grand Junction in the 1930s and 1940s, large congregations of presumably spawning razorback suckers were reported in inundated floodplains (Osmundson and Kaeding 1989a). In the 1970s, several hundred spawning adults were found in a zero-velocity riverside pool near Debeque, Colorado, and eggs were found in the substrate (Osmundson 2001). Razorback suckers in spawning condition were also captured in gravel-pit ponds in the Grand Junction area, but it was unclear if the fish were spawning in the ponds or using the warm, low-velocity habitat to stage for or recover from spawning (McAda and Wydoski 1980; Valdez et al. 1982; Osmundson and Kaeding 1991). Juveniles and adults were captured in Old Charley Wash, a floodplain wetland along the middle Green River, but it was unclear if reproduction had occurred in the wetland or if the juveniles had entered the wetland from the main channel (Modde 1996).

Table 8. Summary of mesohabitats used by life stage of the razorback sucker as described by various investigators.

Life Stage	Summary of Mesohabitats Used		Citation
Spawning Habitat	Spawn on river bars of cobble/gravel mix in Green, Yampa, Upper Colorado, Gunnison, San Juan, and Lower Colorado Rivers.		McAda and Seethaler 1975; McAda and Wydoski 1980; Tyus 1987; Mueller 1989; Tyus and Karp 1990; Modee and Irving 1998; Chart et al. 1999; Ryden 2000; Wydoski and Mueller 2006
	May spawn in gravel pit ponds and floodplain wetlands.		McAda and Wydoski 1980; Valdez et al. 1982; Osmundson and Kaeding 1991; Modde 1996
	In reservoirs spawn along sloping, wave-sorted gravel or cobble shorelines, often in bays, coves, and tributary inflows.		Douglas 1952; Jonez and Sumner 1954; Mueller et al. 1982, 1985, 1998, 2000; Minckley 1983; Medel-Ulmer 1983; Bestgen 1990; Bozek et al. 1991
Drift and Nursery Habitat	In rivers, drift along quiet shorelines in main channels and become entrained in the quiet, warm, shallow waters of floodplain wetlands, backwaters, and tributary mouths, which serve as nursery habitats.		Valdez et al. 1985; Tyus 1987; Mueller 1989; Marsh and Minckley 1989; Bestgen 1990; Gutermuth et al. 1994; Modde 1996; Muth et al. 1998; Wydoski and Wick 1998; Bestgen and Haines 2010
	In reservoirs, emerge along cobble shoals and move toward shorelines, where they rear in warm, shallow backwaters, coves, or tributary inflows.		Minckley 1983; Bozek et al. 1984; Marsh and Papoulias 1989; Pacey and Marsh 1998
Subadults and Adults	In rivers, subadults and adults occupy a variety of generally low-velocity habitats, including runs, eddies, pools, shorelines, mouths of tributaries, backwaters, floodplain wetlands, and gravel pits. They may prefer turbid conditions and soft substrates. In reservoirs, use variety of deep habitats and eddies and pools in intervening river.		Simon 1951; Vanicek 1967; Holden and Stalnaker 1975; McAda and Seethaler 1975; Kidd 1977; Valdez et al. 1982; Tyus 1987; Tyus and Karp 1990; Bradford and Vlach 1995; Burdick and Bonar 1997; Modde and Wick 1997; Modde et al. 1999; Pacey and Marsh 1998; Gurtin and Bradford 2000; Burdick 2002, 2003
Seasonal Use of Rivers by Adults	Spring (high flow)	Low-velocity runs and eddies, backwaters and areas of Inundated vegetation.	Tyus 1987; Osmundson and Kaeding 1989a; Valdez et al. 1982; Miller et al. 1982; Holden and Masslich 1997; Ryden 2000
	Summer (baseflow)	Runs near shorelines, Mid-channel bars. In the San Juan River, fast water runs.	Valdez et al. 1982; Tyus 1987; Ferriole 1988; Osmundson and Kaeding 1989a; Tyus and Karp 1989; Holden and Masslich 1997; Ryden 2000
	Fall	Pool use increased, use of runs decreased.	Osmundson and Kaeding 1989a; Valdez and Masslich 1989
	Winter	Low-velocity runs and eddies, pools and slackwaters. In the San Juan River, pool edges.	Osmundson and Kaeding 1989a; Valdez and Masslich 1989; Ryden 2000

In the San Juan River, hatchery-raised, ripe, male razorback suckers were collected over mid-channel cobble riffles or run/riffles or over cobble shoal/runs at the river's edge along with aggregations of ripe flannelmouth suckers (*Catostomus latipinnis*; Ryden 2000). These captures occurred in May during the ascending limb of the hydrograph, and indicate that razorback suckers in the San Juan River were spawning during increasing spring flows, as they do in the Green River (Muth et al. 1998). Larval razorback suckers have been caught every year in the San Juan River since 1998, indicating that successful reproduction is occurring in that river system (Ryden 2009).

In the Lower Colorado River Basin, razorback sucker spawning has been documented in rivers, reservoirs, and artificial ponds and backwaters (Pacey and Marsh 1998). In the mainstem Colorado River, spawning was documented below Hoover Dam over scoured sand, gravel, and cobbles deposited in the river channel at the mouth of a dry wash (Mueller 1989). Several hundred adults were also found spawning in the river between Davis Dam and Lake Havasu, just upstream of Needles, California (Wydoski and Mueller 2006). As in other areas, spawning was taking place over predominately coarse substrate deposited at the mouth of a wash.

In reservoirs, razorback suckers begin moving in late fall or early winter from relatively deep pelagic waters (≤18.3 m) to congregate and spawn in shallow, littoral zones (0.6–6.1 m) (Jonez and Sumner 1954; Minckley 1983; Mueller and Marsh 1998; Albrecht et al. 2008a). Spawning in lower basin reservoirs can occur as early as late November and extend into May. In Lake Mohave, razorback suckers spawned over cobble shoals from January through April (Mueller and Marsh 1998) and November through May (Bozek et al. 1991). In Lake Mead, spawning occurs in February through April over spawning sites with rocky substrate and vegetation, although the fish may shift locations with changes in reservoir elevation (Kegerries et al. 2009).

In Senator Wash Reservoir, south of Lake Mohave, spawning began in late November and continued through early May, with peak activity in December through March (Kretschmann and Leslie 2006). In Cibola Levee Pond, spawning occurred along the southern portion of the river levee over gravel and cobbles substrate that was cleansed of silt by the movements of spawning fish (Mueller 2006).

Razorback suckers in reservoirs of the Lower Colorado River Basin typically spawn on gentle sloping shorelines with wave-sorted gravel or cobble, often in bays or coves and over debris fans at mouths of ephemeral washes and inflowing rivers (Jonez and Sumner 1954; Minckley 1983; Medel-Ulmer 1983; Bestgen 1990, Bozek et al. 1991). Douglas (1952) observed spawning activity in Lake Havasu in a shallow bay with substrate described as silt over sand intermixed with boulders and gravel. In Lake Mohave, it has been hypothesized that the gravel terraces and shoals along shorelines used for spawning are generated and maintained by wave action, fluctuating water levels, and deposition of new coarse material from flashfloods down tributary washes (Mueller et al. 1982; Bozek et al. 1991).

Notably, spawning has not been documented or suspected in Lake Powell where the shoreline is predominantly steep, vertical canyon walls, and in contrast to Lakes Mead, Mohave, and Havasu, which occur in open basins with low-angle terraces or shoals that are suitable spawning and nursery habitat.

3.2 Larval Drift and Nursery Habitat

Razorback sucker eggs hatch in approximately 6–7 days and the larvae swim up in 10–14 days (Snyder and Muth 1990; Bestgen and Haines 2010). In reservoirs (Bozek et al. 1990) and rivers (Bestgen 1990), the larvae spent daylight hours in interstitial spaces of the substrate and emerged at night to feed. In reservoirs and ponds, larvae and post-larvae have been collected in quiet shoreline habitats, where they remained for a few weeks before moving to deeper water (Langhorst and Marsh 1986; Minckley et al. 1991). In reservoirs, nursery habitat for juveniles most likely occurs in warm, shallow backwaters, embayments, and tributary mouths (Pacey and Marsh 1998).

In rivers, once larvae emerge they become vulnerable to downstream drift, the nature of which depends on current velocity, channel morphology, and the size/age of larvae (Bestgen 1990). Razorback sucker larvae drift along channel margins and colonize quiet, nearshore areas quite rapidly (Bestgen and Haines 2010). Larvae have been collected from low- or zero-velocity habitats such as shallow shoreline eddies, backwaters, gravel pits, and floodplain wetlands in the Green River (Tyus 1987; Gutermuth et al. 1994; Modde 1996; Muth et al. 1998; Bestgen and Haines 2010), upper Colorado River (Valdez et al. 1985), Gunnison River (Burdick 2003), San Juan River (Brandenburg and Farrington 2009), and Gila River (Bestgen et al. 1987).

In studies of larval drift in the Green River, razorback sucker larvae and near-neutrally buoyant artificial beads were released simultaneously to evaluate downstream drift and entrained in floodplain wetlands (Hedrick et al. 2009; Bestgen and Haines 2010). Entrainment occurred to the greatest degree in wetlands nearest to and on the same side of the river as the point of release; however, some beads were detected 53 mi downstream. Hedrick et al. (2009) found that entrainment in floodplain wetlands was most effective when the levee had multiple breaches (flow-through wetlands), allowing water to enter the site on both the ascending and descending limbs of the hydrograph. In contrast, larval razorback suckers in the San Juan River, where large floodplains are absent, are typically found in backwaters and small embayments.

For razorback sucker larvae and young juveniles to survive and grow, they require conditions most likely to be found in floodplain wetlands that include:

- an ample food supply (e.g., algae, phytoplankton, zooplankton, larval chironomids),
- warm water temperatures that allow rapid growth, and
- cover from potential predators (Bestgen 1990; Wydoski and Wick 1998; Muth et al. 1998).

Larval razorback suckers need to feed within 8–19 days of hatching (Papoulias and Minckley 1990, 1992), and main channel habitats typically do not provide sufficient nutrients (Modde 1996, 1997; Mabey and Shiozawa 1993); thus, it is critical for drifting larvae to reach suitable nursery habitat 1–2 days after swim-up (Valdez and Nelson 2004). Historically, floodplains inundated and connected to the main channel by spring runoff likely provided the most important nursery habitat for razorback suckers in the Colorado River System (Modde 1996; Wydoski and Wick 1998), although all juvenile razorback suckers collected in the upper basin by 1997 had come from backwaters (Modde 1997), suggesting that these habitats provide important habitat for the older fish. While much floodplain and backwater habitat has been lost as a result of channelization, levees, and flow regulation, razorback suckers have come to use gravel pits and other artificial, off-channel ponds as a partial substitute (USFWS 2002).

Floodplains, backwaters, and other sheltered habitats are also used by many species of nonnative fish, and predation by these fish has been widely implicated as one of the causes of recruitment failure among larval razorback suckers (e.g., McAda and Wydoski 1980; Marsh and Langhorst 1988; Mueller et al. 2001; Modde and Haines 2005). Juvenile nonnative fish may be the most common predators of larval razorback suckers in nursery areas (Modde and Haines 2005), but adult nonnative fish and other aquatic species (e.g., dragonfly nymphs, crayfish and bullfrogs) also prey on these small fish (Karp and Tyus 1990; Muth 1990; Johnson et al. 1993; Horn et al. 1994; Modde and Wick 1997; Mueller et al. 2006; Carpenter and Mueller 2008). Predation on juvenile razorback suckers by nonnative species is widely thought to be the primary reason that millions of small razorback suckers stocked by agencies have failed to survive (Marsh and Brooks 1989; Pacey and Marsh 1998; Minckley et al. 2003; Mueller 2006).

3.3 Subadults and Adults

Adult and subadult razorback suckers are the most adaptable life stage of the species (Minckley et al. 1991; Modde et al. 1995). In riverine systems, adults use both main channel and backwater habitats (e.g., Valdez et al. 1982; Osmundson and Kaeding 1989a; Tyus and Karp 1990; Minckley et al. 1991; Clarkson et al. 1993; Modde 1996) but generally avoid steep, canyon reaches (Tyus 1987). Low-velocity habitats predominate (Holden and Stalnaker 1975; Tyus 1987; Tyus and Karp 1990; Bestgen 1990; Minckley et al. 1991; Mueller and Marsh 2002), but adults have also been documented in fast runs (Ryden 2000). Adult razorback suckers appear to be relatively sedentary, occupying localized reaches except during spawning season (McAda and Wydoski 1980; Osmundson and Kaeding 1989a). Mueller (2006) has emphasized the importance of backwater habitats to adult razorback suckers, particularly large off-channel backwaters that are generally warmer than the main channel, support more food organisms, and offer a low-velocity refuge for fish to recover after spawning.

Adult razorback suckers in rivers use different habitats seasonally, selecting low-velocity habitats adjacent to shorelines more often in spring than in other seasons (Valdez et al. 1987; Tyus 1987). Historical accounts and more recent surveys indicate that during periods of high flow in spring, adults congregate in eddies and backwaters (including inundated floodplains and gravel pits) removed from main channel currents, and occupy backwaters until those areas are dewatered in summer (Minckley 1983; Valdez et al. 1982; Osmundson and Kaeding 1989a; Tyus and Karp 1989, 1991; Bradford and Vlach 1995). The fish typically move to main channel runs, pools, and eddies (Osmundson and Kaeding 1989a; Burdick and Bonar 1997). Mid-channel habitats associated with submerged sandbars and pools behind boulders and logs are used more often in summer than in other seasons (Tyus 1987; Bestgen 1990; Minckley et al. 1991). Modde and Wick (1997) found most adult razorback suckers in runs, eddies, and eddy fences during both spring and summer. During winter, adult razorback suckers in the Green River occupied a 1- to 3-mi reach of river and used slow runs, slackwaters, and eddies (Valdez and Masslich 1989). In the upper Colorado River, they used pools and low-velocity eddies, also in localized reaches (Osmundson and Kaeding 1989a).

In the San Juan River, stocked, radio-tagged adult razorback suckers during winter and spring selected areas with greater habitat richness, including low-velocity habitats such as edge pools, eddies, pools, and backwaters (Ryden 2000). During summer and fall, when overall flow velocity was low, razorback suckers selected areas with less complex habitats and higher velocity, including runs. Razorback suckers selected inundated vegetation when it was available in June, and likely used this area for feeding and as a refuge from high flows; they also used deep water as cover when turbidity was low (Ryden 2000). In the Verde River, stocked radio-tagged adults tended to move downstream after release and were often found in pools or runs over silt substrates (Clarkson et al. 1993).

Little has been reported regarding habitat use by adult razorback suckers in reservoirs outside of the spawning period; however, in Lake Mead, adults occupy both pelagic and littoral zones, seeking deeper waters (≤18.3 m) in bays during summer and fall, and shallower waters (≤6.1 m) along gravelly or vegetated shorelines and turbid inflows during winter and spring (Albrecht et al. 2008a). In Lake Mohave, Mueller et al. (2000) found that adults used some areas of the reservoir year-round, but used other areas only for spawning or only in the hotter summer months. In general, the monitored fish occupied broad, shallow shoreline habitats but were located closer to the surface in spring and autumn and in deeper water in summer. Mueller et al. (1998) reported that five sonic-tagged juveniles in Lake Mohave moved throughout the pelagic zones for the first week after release but then tended to occupy vegetated areas near the shore.

In Cibola Levee Pond, adult razorback suckers occupied the lower portion of the water column in July, mostly around or under dense vegetation (Mueller et al. 2005). The pond was warm (12–34°C) and offered abundant and diverse cover in the form of submerged vegetation and large rip-rap, natural bank cavities, and beaver dens.

3.4 Synthesis of Mesohabitat Data

A synthesis of mesohabitat use shows that adult razorback suckers in a riverine environment favor the deeper areas of the channel with low to moderate velocity, such as deep runs, eddies, and pools, but use gravel pits, slackwaters, and backwaters when available (Figure 19). Adults in a reservoir/riverine environment use large backwaters (i.e., oxbows, floodplains) as well as side channels, or features that tend to provide depth, low velocity, shelter, and food.

The various investigators may use different criteria to define a mesohabitat type, and comparisons of these datasets may not be concise but offer a good insight into the types of mesohabitats used by the species in different settings. It is reasonable to surmise that adult razorback suckers favor deep, quiet areas in the river channel as well as off-channel areas, when available. This species clearly does not favor moderate or high-velocity mesohabitats, such as riffles used by other sucker species of the Colorado River System including the bluehead sucker (*Catostomus discobolus*) (Bezzerides and Bestgen 2002).

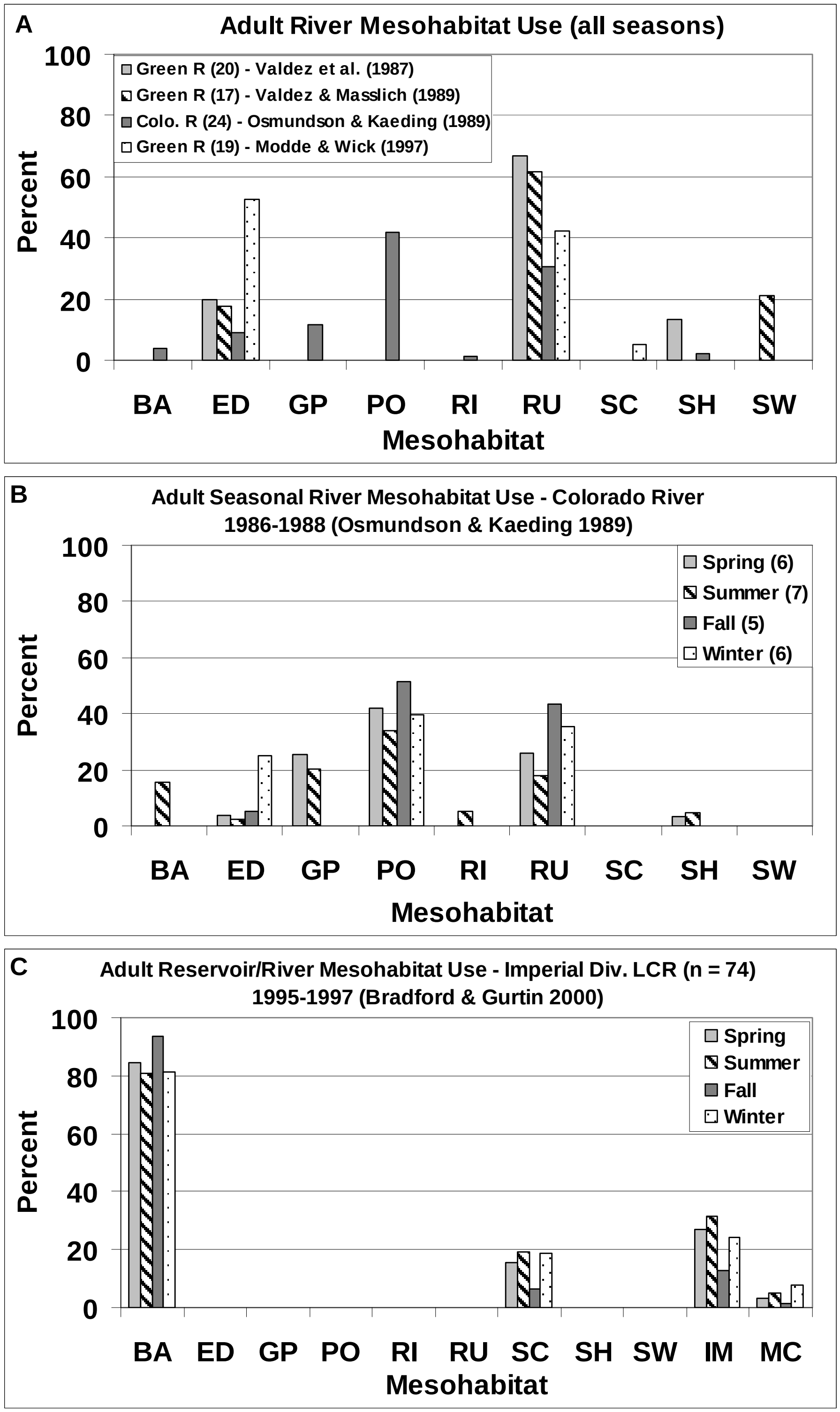

Figure 19. Mesohabitat used by adult razorback suckers in (A) rivers for all seasons, (B) rivers by season, and (C) reservoir/river for all seasons. Data sources are cited in each figure and provided in Appendix A. BA=backwater, ED=eddy, GP=gravel pit, PO=pool, RI=riffle, RU=run, SC=side channel, SW=slackwater, IM=impoundment, MC=main channel.

4.0 MICROHABITAT USE BY LIFE STAGE

The term microhabitat is used in this report to describe the quantifiable physical attributes of mesohabitats used by razorback sucker. These include depth, velocity, substrate, and water temperature. A summary of microhabitats used by various life stages of the razorback sucker is provided in Table 9. Microhabitat and mesohabitat used by various life stages of the razorback sucker are summarized in Section 5.0 and compared with mesohabitat availability in lower Grand Canyon.

Cover is an important habitat variable in addition to temperature, depth, velocity, and substrate; however, the scientific literature has rarely included quantitative data for cover conditions. For this reason, information related to cover is not included in the following tables. Nonetheless, cover is an important component of razorback sucker habitat, particularly for larvae and juveniles which have been observed seeking cover in submerged vegetation, woody material, or debris (Muth and Wick 1997; Mueller 2003). Mueller and Marsh (1998) reported that juveniles were concealed in vegetation during daylight hours and emerged at night, presumably to feed. They have also been collected in turbid conditions in the shelter of large boulders (Gutermuth et al. 1994), presumably using low water clarity as cover from predators. Adult razorback suckers have showed similar behavior, seeking vegetative and rocky cover during the day (Mueller et al. 2003).

Cover provided by turbidity likely increases survival rates of young fishes by reducing the feeding efficiency of sight-based predators (Dill 1944; Johnson and Hines 1999; Albrecht et al. 2008a). Turbid conditions at the inflows of Las Vegas Wash and the Muddy River/Virgin and Colorado rivers are believed to be a beneficial factor in recent recruitment of razorback suckers in Lake Mead, particularly when the reservoir elevation is low and receding, as in recent years (Albrecht et al. 2008a, 2010; Kegerries et al. 2009). As the lake recedes, formerly submerged fine sediment deposits are increasingly exposed to erosion and suspension by river currents and wave action, resulting in increased turbidity levels at the inflow.

4.1 Spawning

Razorback suckers spawn in rivers of the Upper Colorado River Basin from early April through early June on the ascending limb of hydrograph, with highest activity in mid through late May (Table 9). Spawning takes place at a wide range of water temperatures (6–21°C), at shallow depths (<1.0 m), in low current velocities (<1.0 m/s), and on substrates of small-to-large cobbles, gravel, or cobble/gravel mix.

In the Lower Colorado River Basin, spawning in rivers and reservoirs occurs somewhat earlier (most commonly from late January/early February to mid-March) and at somewhat higher temperatures (6.6–25.5°C). Spawning in the lower basin takes place at shallow depths, in currents of low or zero velocity, and on gravel and gravel/cobble substrates. In both riverine and lacustrine environments, spawning substrate consists of loose, rocky material relatively free of silt, which is cleared away by hydrologic processes (river currents, wave action) and by the agitation of spawning fish. Clean substrates with deep interstitial voids are needed to prevent eggs and larvae from suffocating (Tyus and Karp 1989; Severson et al. 1990).

Although evidence of spawning activity (e.g., congregations of ripe fish) has been documented in the field over a wide temperature range (6–25.5°C), laboratory tests suggest that successful hatching of razorback sucker eggs, and therefore successful reproduction, occurs most often within a narrow range. As shown in Table 10, hatching rates were highest at 20–23.5°C, survival of eggs was poor at 10–12°C and most or all eggs died at 5–10°C and 30°C. Moreover, Marsh (1985) found a significantly lower incidence of deformed larvae at 20°C than at either 15°C or 25°C, and Bozek et al. (1984) found that hatching and development times were significantly lower at 20°C than at 10°C. While the available data suggest that the optimal temperature for reproductive success is near 20°C (Osmundson 2001) or 20–22°C (Hamman 1985; Bozek et al. 1990), lower water temperatures (>10°C) apparently do not preclude successful spawning (Bozek et al. 1990).

4.2 Larval Drift and Nursery Habitat

Larval razorback suckers in the Green River have been collected at water temperatures ranging from 11.0°C to 24.4°C, at varying but mostly shallow depths, in low- or zero-velocity current, and over silt substrate (Table 11). Larvae survived and grew in Old Charley Wash, a managed floodplain wetland adjacent to the Green River, at temperatures ranging from about 11°C to 29°C, and water depths of 0.4 m to 2.3 m (Modde 1997).

In The Stirrup, another managed floodplain wetland, larvae were reared in warm (19–28°C), shallow water (1.0 m) (Christopherson et al. 2004). In Lake Mead, larvae are generally found along shorelines with inundated terrestrial vegetation and high levels of turbidity that provide littoral nursery cover for larval and juveniles, allowing them to avoid predation (Albrecht et al. 2010b).

Juvenile razorback suckers have been collected in very warm water temperature (21.7–34.0°C), at shallow depth (0.1–0.2 m), in zero-velocity current, over silt substrate (see Table 11). Juvenile razorback suckers stocked in June into Humphrey Pond, a gravel-pit pond adjacent to the lower Colorado River, survived and grew in water temperatures that ranged from 26°C down to ~3°C the following January (Osmundson and Kaeding 1989b).

As expected for a warm-water species, young razorback suckers generally fare better in warm temperatures than in cool temperatures. The lengths, weights, and growth rates of larvae and young juveniles in the laboratory were significantly higher at 20°C than at 10°C and 14°C (Clarkson and Childs 2000).

Table 9. Microhabitat data for spawning razorback suckers, Upper and Lower Colorado River Basins.

Location	Timing	Temperature	Depth	Velocity[1]	Substrate	Citation
Upper Colorado River Basin						
Middle Green River	Mid-Apr to late Jun; (mostly mid-May to late May; ascending limb of hydrograph)	8.0–19.5°C	0.2–1.0 m	0.1–1.4 m/s	Coarse sand/ gravel/cobbles	Vanicek 1967; Tyus 1987; Muth et al. 1998; Tyus and Karp 1990; Bestgen et al. 2002; Bestgen and Haines 2010
Lower Green River	Early Apr to early Jun	6.0–21.0°C	-	-	-	Muth et al. 1998; Bestgen et al. 2002
Green River Hatching	Late Apr to early Jun (mean 26 May)	12.0–16.0°C (mean 14.3°C)	-	-	-	Bestgen and Haines 2010
Yampa River	Late Apr to late May (Ascending limb of hydrograph)	6.0–16.0°C	0.7–1.0 m	0.64–1.0 m/s	Small to large cobbles	McAda and Seethaler 1975; Seethaler et al. 1979; McAda and Wydoski 1980; Tyus and Karp 1989; Tyus and Karp 1990
Upper Colorado River	Late Apr to late May	12.4–19.0°C	0.6–1.0 m	0.9 m/s	Cobbles, gravel	Wick et al. 1982; McAda and Seethaler 1975; Osmundson and Seal 2009
Gunnison River	Mid-Apr to late May	11.4–12.3°C	-	-	-	Osmundson and Seal 2009
San Juan River	Apr to May	-	<1.0 m	-	Cobbles	Ryden 2000, 2001
Lower Colorado River Basin						
Lower Colorado River mainstem	Early Feb to mid-Mar	-	0.75–1.0 m	0.0–0.37 m/s	Sand, gravel, cobbles	Mueller 1989; Wydoski and Mueller 2006
Lake Mead	Early Feb to mid-Mar	12.0–18.0°C	0.6–5.0 m	-	Gravel	Jonez and Sumner 1954
Lake Mohave	Nov to May (Peak Jan to Mar)	9.5–22.0°C	<2.75–5.0 m	-	Coarse, wave-washed cobble and gravel	Minckley 1983; Mueller et al. 1982, 1985; Bozek et al. 1984, 1991; Bestgen 1990; Minckley et al. 1991
Lake Havasu	March	14.4–18.3°C	0.25–1.8 m	-	Silt over sand and gravel	Douglas 1952

Location	Timing	Temperature	Depth	Velocity[1]	Substrate	Citation
Senator Wash Reservoir	Late Nov to early May, with peak Dec to Mar	6.6–25.5°C	0.6–5.5 m	-	Mixed medium- size cobble and gravel, with slopes of 30–45%	Medel-Ulmer 1983; Kretschmann and Leslie 2006
Cibola Levee Pond	-	-	>1.5 m	-	Gravel/cobble	Mueller et al. 2005

[1] Velocity usually measured at surface or mid-column and is likely greater than at the level occupied by the fish (Osmundson and Kaeding 1989a; Bradford and Vlach 1995)

Table 10. Hatch success rates by temperature in laboratory trials.

Temperature	Citation
95% hatch success at 14.4–17.2°C; Poor success at 11.6°C	Toney 1974
Spawning: 10.0–15.0°C; Hatching: 17°C (10–20% egg survival at 14.0-16.0°C); Clean gravel 0.6–10.2 cm diameter	Inslee 1981
46% hatch success at 20.0–23.5°C	Loudermilk 1981
Hatch at 20.0–22.00°C	Hamman 1985
High success at 20.0°C (35%) and 25.0°C (29%); Lower: 15.0°C (19%); Egg mortality: 5.0°C, 10.0°C, and 30.0°C	Marsh 1985; Marsh and Pisano 1985
High success: 20.0°C (34–65%); Lowest: 10.0°C 9; Egg mortality: 8.0°C	Bozek et al. 1990
75% hatch success at 20.0°C	Severson et al. 1990
48% hatch success at 12°C and 67% at 20°C	Haines 1995

Table 11. Microhabitat data for larval and small juvenile razorback suckers.

Location	Timing	Temperature	Depth	Velocity	Substrate	Citation
Larvae						
Green River		-	0.3 m	0.06 m/s	Silt	Holden 1977
Old Charley Wash	Spring–summer	11–29°C	~0.4–2.3 m	-	-	Modde 1997
The Stirrup	Mar to Aug	19–28°C	1.0 m	-	-	Christopherson et al. 2004
Lower Colorado River	Late March	11.4°C–17.4°C	-	-	-	Schooley et al. 2008
	Mid-June	21.1–24.4°C on shoreline while mainstem 15.5°C mean	<1.0 m	-	-	Sigler and Miller 1963
Lower Basin	-	12.0–20.0°C	-	-	-	Pacey and Marsh 1998
Lake Mohave	Late Jan to early May	11.0–15.0°C	Most at ~1 m, many at 2.8 m, some at 4.9 m and 6.1 m	-	Mostly gravel/sand	Bozek et al. 1984
Juveniles						
Location	Timing	Temperature	Depth	Velocity	Substrate	Citation
Lower Green River	30 July	34.0°C	0.1–0.2 m	0.0 m/s	Silt	Guterrmuth et al. 1994
Lower Colorado River (Humphrey Pond)	Year-round	26.0°C(Jun); ~3°C (Jan)	1.4–2.0	–	–	Osmundson and Kaeding 1989b
Lower Colorado River	-	21.7–24.4°C	-	-	-	Sigler and Miller 1963

4.3 Subadults and Adults

Adult razorback suckers in the wild appear to tolerate a wide range of water temperatures (0–27°C) (Table 12). Laboratory studies indicate preferred temperatures of 22.0–24.8°C for both adults and subadults, with lower avoidance temperatures at 8.0–14.7°C, and upper avoidance temperatures at 27.4–31.6°C (Table 13). Swimming ability of adults was optimal at 20–26°C and poor at 14°C (Bulkley et al. 1981).

In riverine environments, adults are generally found in deep water, but can be found in a range of depths (0.18–3.4 m), with no consistent seasonal pattern across studies. Depths occupied in summer in the San Juan River were similar to those occupied in winter in the upper Colorado River. There was, however, a strong relationship between season and depth in Lake Mead, where fish used deeper water in the hot summer months (9.1–18.3 m) than in cool winter months (1.5–6.1 m). Reported current velocities were uniformly low (<1.0 m/s) and substrates consisted predominately of sand and silt.

4.4 Synthesis of Microhabitat Data

Data on water depth, velocity, and substrate used by the razorback sucker were assimilated from various investigations and are provided in Figures 20–22. Depths used by adults ranged from shallow water to about 11.5 ft, but the majority of fish were found at depths that ranged from about 2 to 4.5 ft (Figure 20). Seasonal data were based on four radio-tagged adults, which tended to use deeper water ranging from 3 to 7 ft, with deeper water being used in fall and winter. As expected, larvae used water that was 1 ft or less, but were found in water as deep as 5 ft where vegetative cover was present.

Water velocity used by most adult razorback suckers ranged from 0 to about 2 ft/sec (Figure 21). Water velocity recorded was either at the fish location in the water column, or at 0.6 of the water depth which may not reflect the velocity at the actual fish location. These different methods for measuring water velocity may explain the range of values seen in Figure 21. Nevertheless, these datasets indicate that the species favors low velocity areas, not necessarily absent of water velocity. As expected, all larvae were found at water velocities at or near 0 ft/sec.

Substrate used by adult razorback suckers in all seasons showed a strong selection for silt and sand, with less use of gravel and cobble (Figure 22). These substrate types are consistent with mesohabitat selection of slow deep habitats and low to moderate water velocities, which help to shape the types of substrates in the channel. It should be noted that despite their apparent year-around use of finer substrates (i.e., silt and sand), razorback suckers are known to spawn only on rocky substrates consisting of cobble and gravel (in rivers) or imbricated rock talus (in reservoirs). Also, investigators consistently report selection by larvae for vegetative cover, which was not sufficiently quantified to provide in this report, as was done for depth, velocity, and substrate.

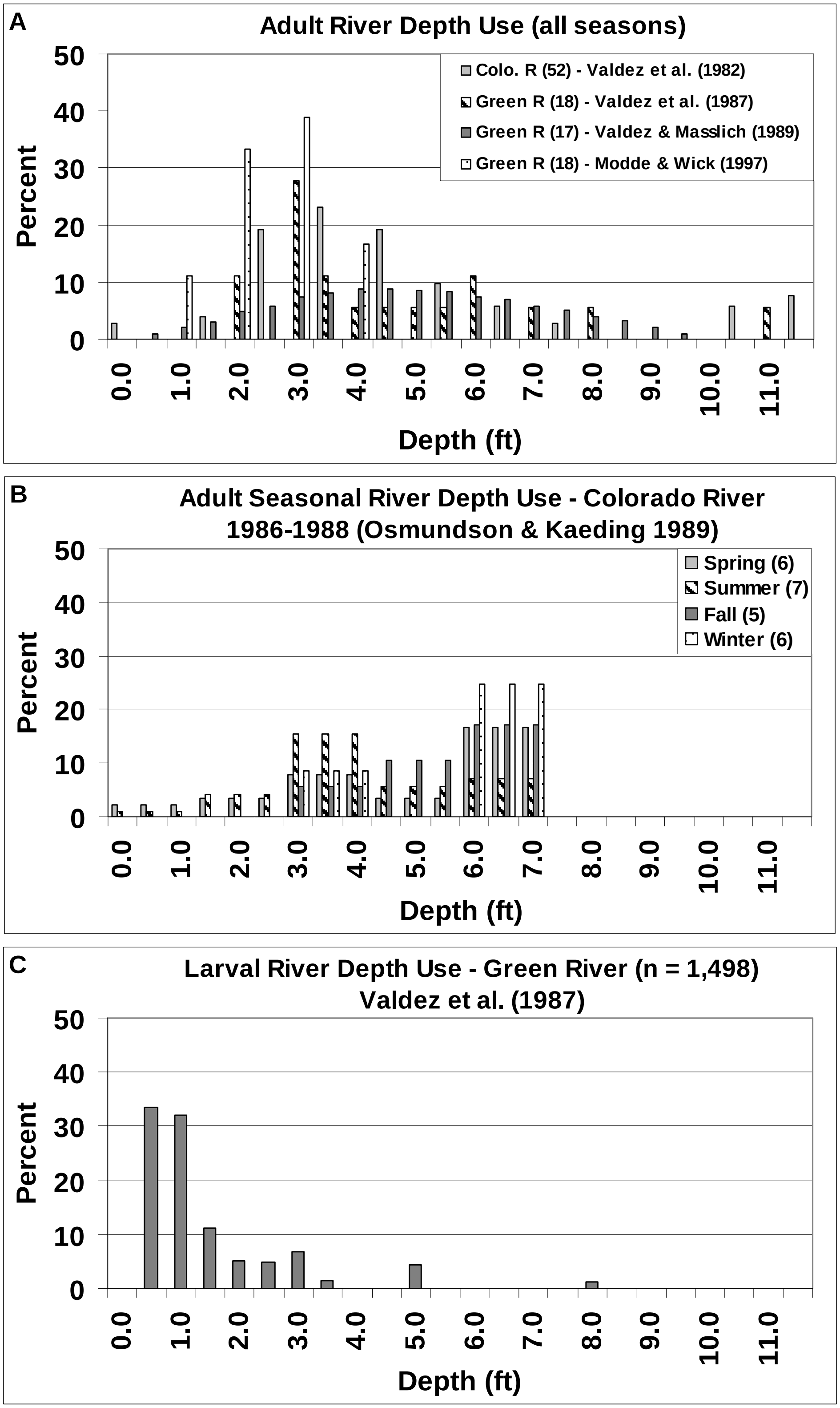

Figure 20. Depth used by (A) adult razorback suckers in rivers for all seasons, (B) adults in rivers by season, and (C) larvae in the Green River. Data sources are cited in each figure and provided in Appendix A.

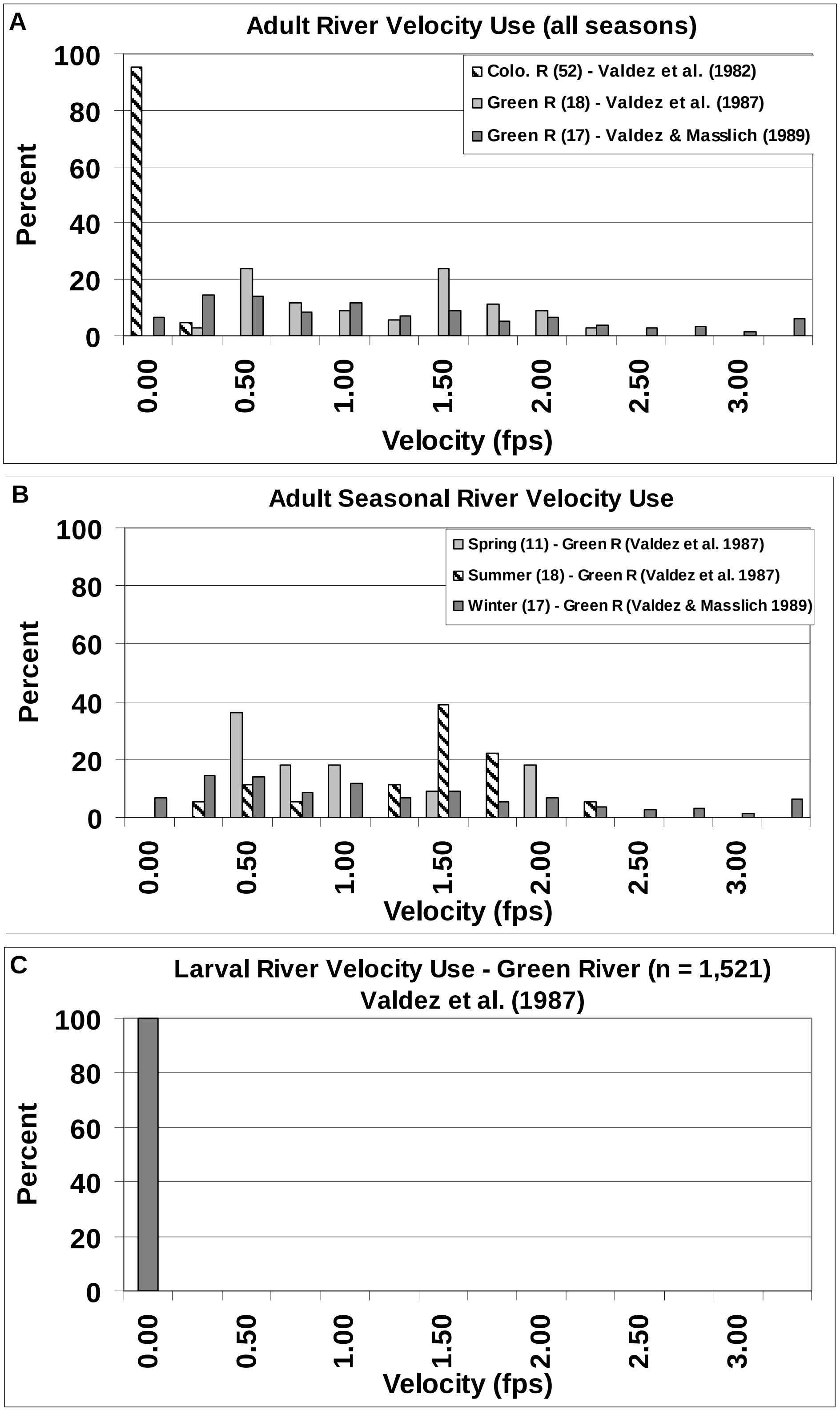

Figure 21. Velocity used by (A) adult razorback suckers in rivers for all seasons, (B) adults in rivers by season, and (C) larvae in the Green River. Data sources are cited in each figure and provided in Appendix A.

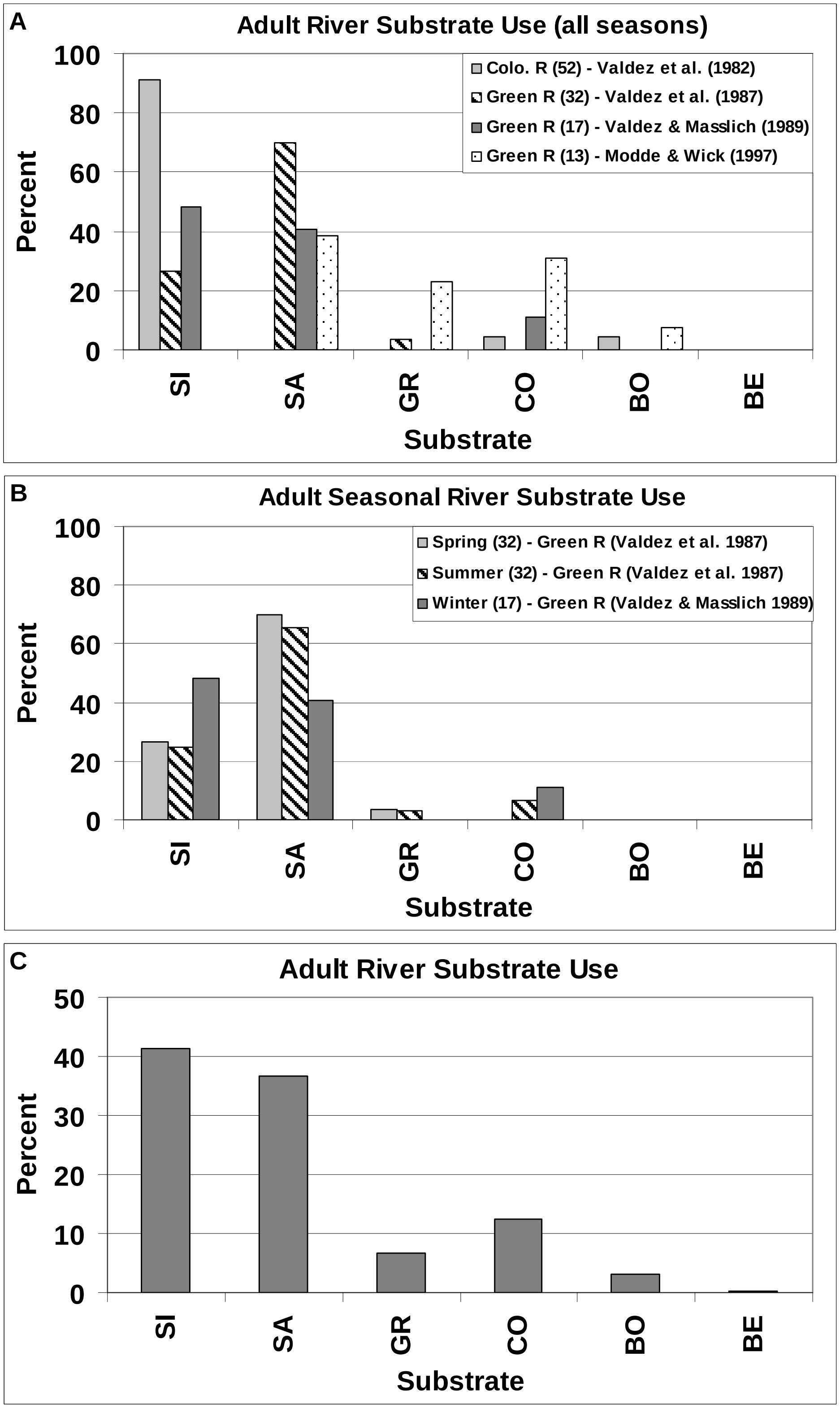

Figure 22. Substrate used by (A) adult razorback suckers in rivers for all seasons, (B) adults in rivers by season, and (C) adults in all rivers and seasons. Data sources are cited in each figure and provided in Appendix A. SI=silt, SA=sand, GR=gravel, CO=cobble, BO=boulder, BE=bedrock.

Table 12. Microhabitat data for large juvenile and adult razorback suckers.

Reach	Timing	Temperature	Depth	Velocity[1]	Substrate	Citation
Green River	Apr to Nov	-	0.18–3.0 m	0.0–0.7 m/s	Sand, silt, sand/silt mixed; some gravel; mud/cobble in gravel pit; boulders in Split Mountain Canyon	Tyus et al. 1981, 1982; Tyus 1987; Modde and Wick 1997
	Nov to Mar	0.0-10.5°C	0.4–1.8 m	Primarily 0.0–0.4 m/s	Sand, silt; some cobble	Valdez and Masslich 1989
Yampa	-	-	0.6–3.4 m	-	Sand, silt	Tyus and Karp 1989
Upper Colorado River	Mid-March through Late October	7.8–27.0°C	0.8–2.0 m (common); 1.0–1.7 m (peak use)	90% in 0.0 m/s; 19% in 0.03–0.61 m/s	Silt dominant	Valdez et al. 1982
	Spring	-	0.9–2.3 m	<0.3 m/s	Mostly silt/sand; some cobble	Valdez et al. 1987; Osmundson and Kaeding 1989a
	Summer/fall	11.5–12.5°C	0.6–3.0 m	0.34–0.52 m/s	Mostly silt and sand; some gravel/rubble; mud/cobble in shallowest area of gravel pit	McAda and Wydoski 1980; Valdez et al. 1987; Osmundson and Kaeding 1989a
	Winter	-	1.86–2.19 m	-	Mostly silt and sand	Osmundson and Kaeding 1989a
San Juan River	Mar to May	10.9–14.8°C (mean)	0.7–0.8 m (mean)	0.3–0.5 m/s (mean)	-	Ryden 2000
	Jun to Aug	15.0–23.7°C (mean)	1.2–1.9 m (mean)	0.5–0.6 m/s (mean)	-	
	Oct and Nov	5.3–11.5°C (mean)	1.2 m (mean)	0.5 m/s (mean)	-	
	Dec to Feb	1.3–4.3°C (mean)	0.8–1.1 m (mean)	0.2–0.5 m/s (mean)	-	
Verde River	-	-	0.60–1.19 m	<0.1 m/s	Mostly silt/sand; some gravel/cobble	Clarkson et al. 1993

Reach	Timing	Temperature	Depth	Velocity[1]	Substrate	Citation
Gila River	-	-	<0.4 m	0.1–0.2 m/s	65% sand, 20% gravel, 5% silt, 5% cobble	Marsh and Minckley 1989
Lake Mead	Fall and summer	-	9.1–18.3 m	-	-	Albrecht et al. 2008a
	Winter and spawning season	-	1.5–6.1 m	-	-	

[1] Velocity usually measured at surface or mid-column and is likely greater than at the level occupied by the fish (Osmundson and Kaeding 1989a)

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Table 13. Temperature preference and swimming ability data for large juvenile and adult razorback suckers from laboratory trials.

Study Parameter	Study Finding	Citation
Temperature Preference	Subadults (150–300 mm) preferred 22.0–23.0°C	Valentine 1981
	Subadults (150–300 mm) preferred 23.0–24.0°C	Bulkley et al. 1981
	Adults preferred 22.9–24.8°C Upper avoidance: 27.4–31.6°C Lower avoidance: 8.0–14.7°C	Bulkley and Pimentel 1983
	Adults preferred 23–24°C	Black and Bulkley 1985
Swimming Performance	Optimal swimming ability: 20.0–26.0°C Poorer swimming performance at 14.0°C	Bulkley et al. 1981

5.0 RAZORBACK SUCKER IN LOWER GRAND CANYON AND LAKE MEAD

5.1 Occurrence of Razorback Sucker in Grand Canyon

Ten documented records exist for the razorback sucker between Glen Canyon Dam and the upper extent of the Lake Mead inflow (Valdez 1996; Valdez and Carothers 1998; Figure 23):

- one adult caught by an angler in Bright Angel Creek in 1944 (Minckley and Carothers 1979);
- one captured by the AGFD at the mouth of the Paria River just after closure of Glen Canyon Dam in 1963 (Minckley and Carothers 1979);
- three adults, including a gravid female, from the mouth of the Paria River in June 1978 (Minckley and Carothers 1979);
- one adult from near lower Bass Camp (RM 108) in April 1984 (Maddux et al. 1987);
- one female (555 mm TL, 1,860 gm) from the Little Colorado River (LCR) inflow in May 1989 (C.O. Minckley, USFWS, pers. comm., as cited in Valdez and Carothers 1998); and
- three adults from the LCR inflow in April 1990, including two males (475 mm TL, 1,211 gm; 476 mm TL, 1,219 gm) and one female (588 mm TL, 2,035 gm) (W. Persons, AGFD, pers. comm., as cited in Valdez and Carothers 1998).

All confirmed razorback suckers captured in were adults, suggesting that either the reach is not used as rearing habitat or reproduction and recruitment do not occur in this region of the Colorado River (Valdez and Carothers 1998). More than a decade ago, Valdez (1996) surmised that fewer than 100 razorback suckers probably remained in Grand Canyon, and the species was nearing extirpation from this reach. Douglas and Marsh (1996) conjectured that razorback suckers were never abundant in Grand Canyon, occupying the area as transients rather than residents, moving between more desirable habitats upstream and downstream.

Numerous morphologic intergrades or apparent hybrids between the razorback sucker and the more common flannelmouth sucker have been reported from the Grand Canyon (Suttkus et al. 1976; Maddux et al. 1987; Valdez and Ryel 1995), as well as from various parts of the Colorado River System (Minckley et al. 1991). Larval suckers collected at the mouths of the LCR and Havasu Creek in the late 1990's were either razorback suckers or hybrids of razorback sucker and flannelmouth sucker (Douglas and Douglas 2000).

One of the last razorback suckers documented in the Grand Canyon was an adult captured in the Colorado River near lower Bass Camp (RM 108) by S.W. Carothers and C.O. Minckley in April 1984 (Maddux et al. 1987). Adult razorback suckers have been caught recently in the Colorado River inflow (Figure 24). These fish moved from the Lake Mead populations in Echo Bay and Las Vegas Wash, and the presence of larvae in 2000, 2001, and 2010, as well as ripe and gravid fish in 2010 indicates that a cobble/gravel island between Devil's Cove and North Bay is being used for spawning (Kegerries et al. 2009; Albrecht et al. 2010a, 2010b).

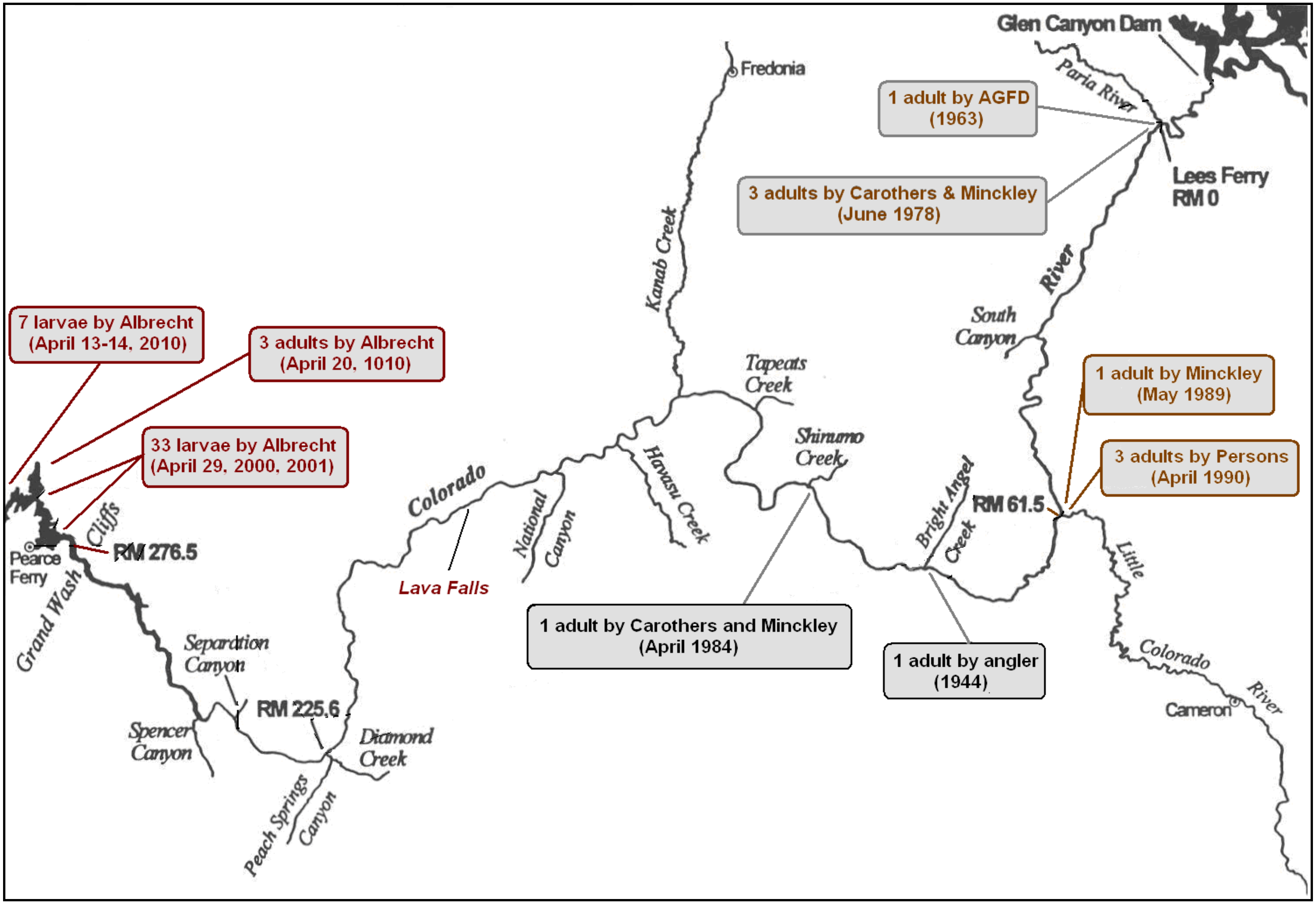

Figure 23. Capture locations of razorback suckers in Grand Canyon and the Lake Mead inflow.

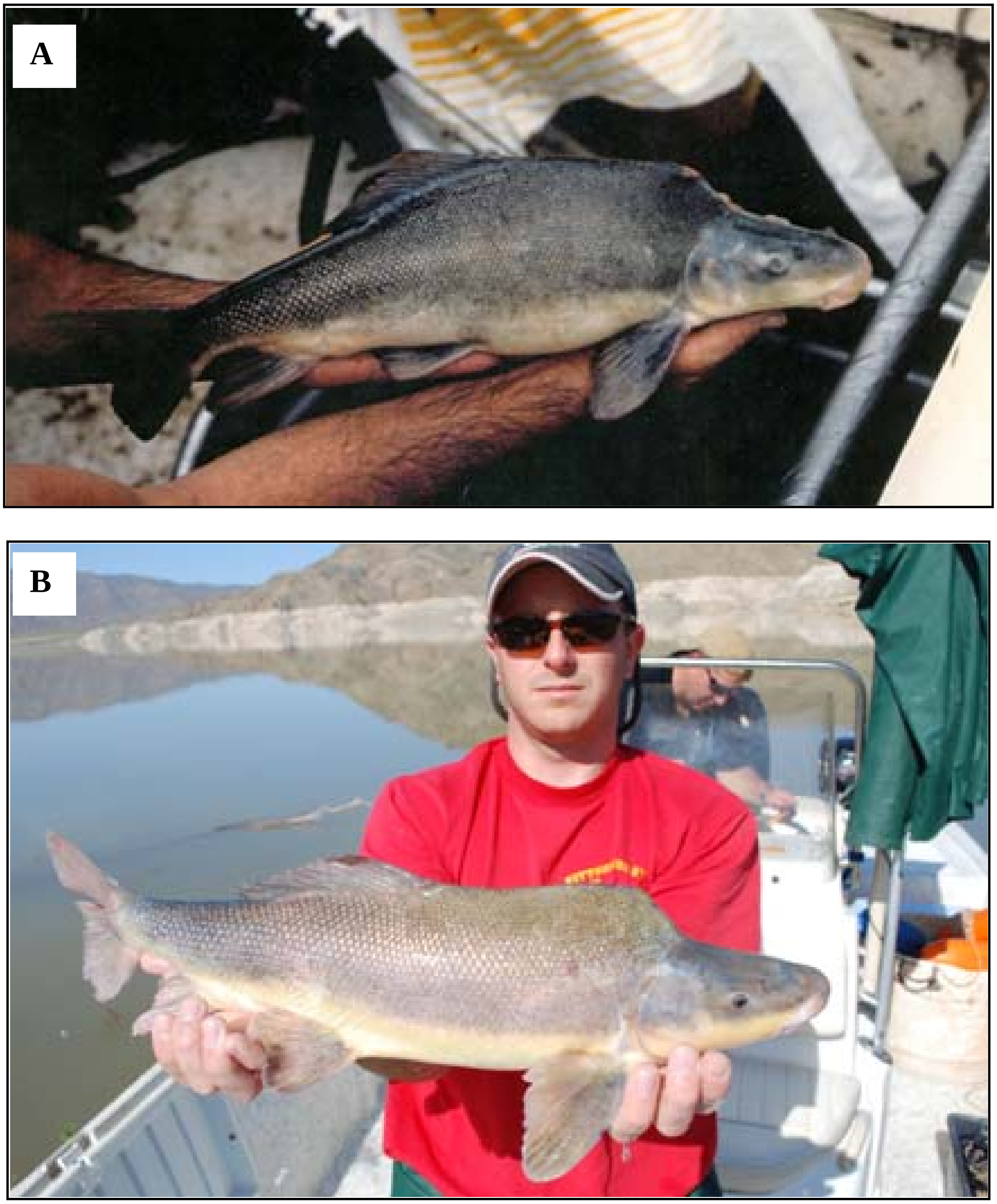

Figure 24. Photographs of (A) one of the last razorback suckers captured in the Colorado River in Grand Canyon near lower Bass Camp (RM 108) by S.W. Carothers and C.O. Minckley in April 1984 (Maddux et al. 1987), and (B) a razorback sucker captured by Bio/West biologists in April, 2010 in the Colorado River inflow below Iceburg Canyon. Photos courtesy of S.W. Carothers and B.A. Albrecht, respectively.

5.2 Studies of Razorback Sucker in Lower Grand Canyon

5.2.1 Fisheries Surveys

The razorback sucker has been absent from all fisheries surveys of the lower Grand Canyon (i.e., Lava Falls rapid to Lake Mead inflow; see section 6.3.2). Fisheries investigations during the 1970s failed to capture or observe the species in this region of the Colorado River (Carothers and Minckley 1981; McCall 1980; Bookstein 1985). Intensive sampling from Diamond Creek to Pearce Ferry from June 1992 through January 1994 also did not report razorback suckers (Valdez 1994; Valdez et al. 1995), nor did more contemporary surveys during 2004–2006 (Ackerman et al. 2006; Ackerman 2007), and 2005 (Rogers et al. 2007).

Razorback suckers, however, have been caught annually in Lake Mead since 1990, although none were caught in the Colorado River inflow until 2000; the first individuals caught were larvae and not adults. Altogether, 33 larvae were found in the inflow in 2000 (11) and 2001 (22), but no adults were detected despite considerable netting efforts (Albrecht et al. 2008a) until 2008 when the AGFD captured a large adult during annual gill netting in Gregg Basin. In 2010, two sonic-tagged adults, originally stocked into the Muddy River/Virgin River inflow area (one fish, code 3354) and Las Vegas Bay (one fish, code 465), were contacted in Gregg Basin near the Colorado River inflow. These findings provide evidence that wild razorback suckers may occur in various part of Lake Mead and that lake-wide movement of stocked fish may lead investigators to these wild fish. The strategy of translocating wild fish sonic-tagged fish is being employed in Lake Mead to reveal aggregations of wild fish and possible spawning locations. In May and June of 2010, four fish were sonic-tagged and release in Gregg Basin, and four were tagged and released in the Colorado River inflow, but the subsequent contact information from these fish was not available for this report.

Prior to about 2000, few razorback suckers were evidently using the Colorado River inflow. Changes in lake elevation and movement of fish from the Las Vegas Bay, Echo Bay, and Muddy River/Virgin River populations may have lead to fish moving to the inflow. The first suspected spawning site in the Colorado River inflow was identified in upper Gregg Basin in 2010, and larvae were captured near the site in 2000, 2001, and 2010. Given the size and continuous flow of the Colorado River through lower Grand Canyon, it is not unreasonable to expect that razorback suckers could use the entire inflow area—including the river in lower Grand Canyon.

5.2.2 Studies of Movement and Habitat Use

One study in 1997 attempted to evaluate potential habitat use and movement of the species in the region. On June 24, 1997, the Hualapai Tribe with assistance from SWCA and Reclamation released 15 radio-tagged adult razorback suckers into the Colorado River in lower Grand Canyon (Unpublished data, SWCA Environmental Consultants, Flagstaff, AZ). Five fish were released at each of three sites: Spencer Canyon (RM 246), Quartermaster Canyon (260.1), and Separation Canyon (239.6).

Over 15 weeks, 12 of the fish were detected a total of 48 times. The net distance traveled from each release site ranged from 0 to 26.7 mi, with 4 of the 12 fish last detected at or upstream of the release site and 8 last detected downstream (Table 14; Figure 25). Of the seven fish tracked over the longest period (≥69 days), five traveled relatively long distances (23.0–26.7 mi), two traveled moderate distances (6.4–11.1 mi), and one traveled only 2.3 mi in 104 days.

Six of the 12 tagged fish remained or moved into a region downstream of Quartermaster Canyon (RM 260), which in 1997 was a slow-flowing, semi-turbid lake environment, well below the interface of the Colorado River and Lake Mead (i.e., 1,203.7 ft, about RM 241, below Separation Canyon). Their movement into and use of this area is not explained, but the fish moved from portions of the river channel that had been filled with sediment into a more diverse area with vegetated shorelines. In contrast, subsequent fisheries surveys in 2009 were conducted at a lower lake elevation when the river/lake interface was about 20 mi downstream (i.e., 1,099.1 ft, about RM 261, below Quartermaster Canyon) and the river had carved a channel into the sediment exposing the original diverse river bottom and shoreline features. Because of these extensive geomorphic changes to the lower Grand Canyon, the 1997 radio-telemetry study of razorback suckers may not be representative of what the fish might do in the contemporary river setting.

Table 14. Movement of radio-tagged adult razorback suckers in lower Grand Canyon, June–October, 1997. Hualapai Aquatic Studies. Unpublished data, SWCA Environmental Consultants.

Fish Tag Frequency	Release Site (RM)	Last Observation (RM)	Days since Release	Net Movement (River Miles)	Direction of Movement
40.011	239.6	266.3	83	26.7	Downstream
40.021	239.6	240.5	1	0.9	Downstream
40.031	239.6	265.0	83	25.4	Downstream
40.051	239.6	238.0	7	1.6	Upstream
40.120	239.6	246.0	103	6.4	Downstream
40.061	246.0	271.0	104	25.0	Downstream
40.081	246.0	248.3	104	2.3	Downstream
40.141	246.0	246.0	1	0	No Movement
40.150	246.0	242.5	8	3.5	Upstream
40.091	260.2	260.2	8	0	No Movement
40.101	260.2	285.0	69	24.8	Downstream
40.131	260.2	271.3	83	11.1	Downstream

The radio-telemetry study also provided some information on habitat use. The radio-tagged fish were contacted primarily in eddies (38%), and in pools, slackwaters, and "lake" habitat (31%; Table 15). Vegetated banks were the most common shoreline type used and about 18% of the fish were detected in submerged vegetation. This association with vegetation indicates that in 1997 the fish relocated in the area below Quartermaster Canyon where habitat was more diverse and vegetative cover was more available.

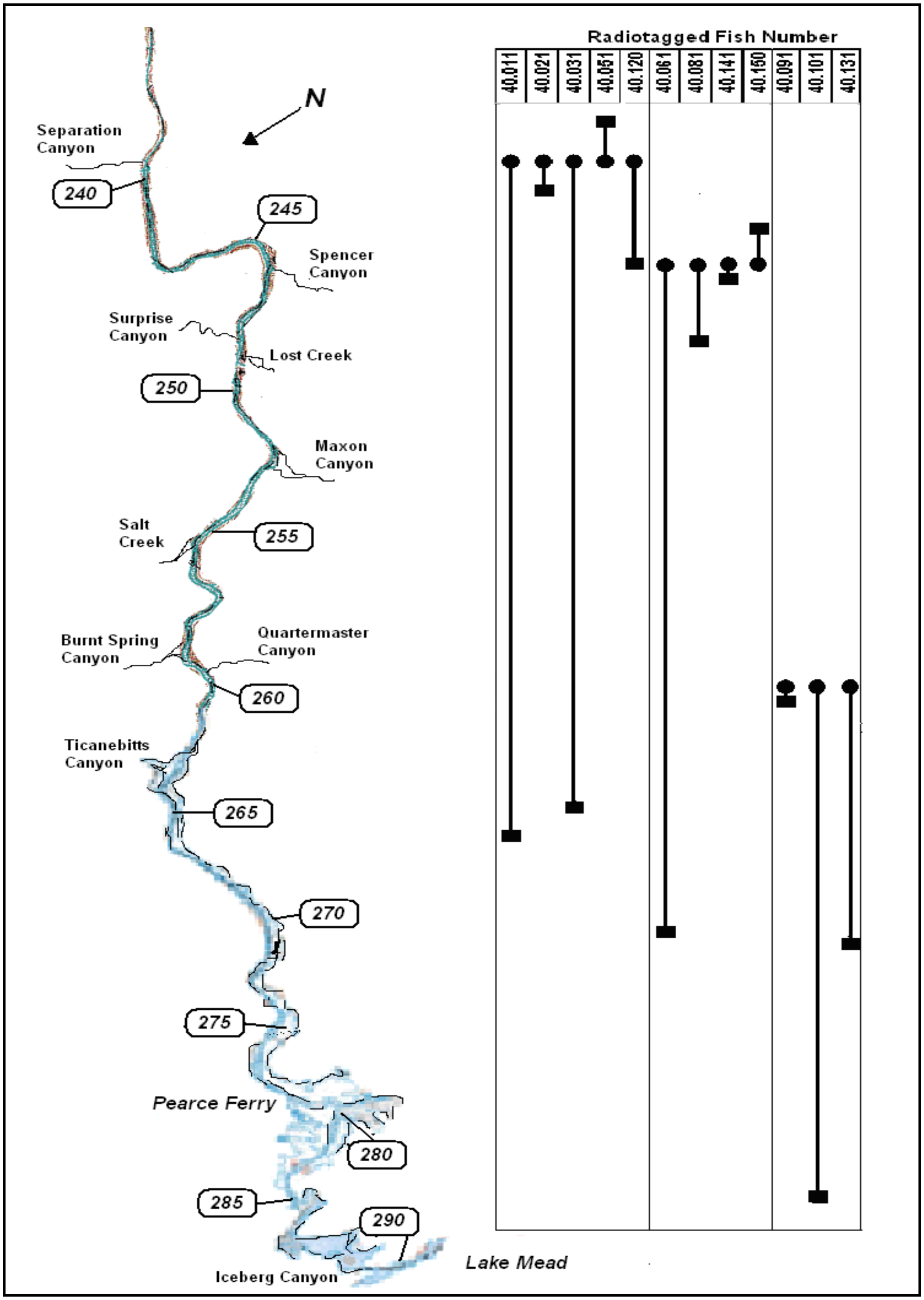

Figure 25. Net movement of 12 radio-tagged adult razorback suckers in lower Grand Canyon and Colorado River inflow, June–October, 1997 (see Table 14 for movement data). Release locations indicated by black circles; last contacts indicated by black rectangles. Map to approximate scale; river miles (RM) 240–290 (shown in boxes) are distances downstream from Lees Ferry.

Table 15. Habitat associations of radio-tagged adult razorback suckers in lower Grand Canyon, June–October, 1997; Hualapai Aquatic Studies. Unpublished data, SWCA Environmental Consultants.

Fish	Habitat	Shoreline Type	Temp (C)	Substrate	Turbidity	Shade	RM	Location Comments
0.041	ED	SA,VG		SA			246.0	Above Mouth of Spencer
0.081	ED						245.9	
0.061	ED						246.2	
0.141	ED	SA,VG		SA			246.0	Above Mouth of Spencer
0.150	ED	SA,VG		SA			246.0	Above Mouth of Spencer
0.011	ED						239.6	
0.021	ED						239.6	
0.120	TS				L	H	240.0	
0.141	ED	Rock face					245.8	Above Spencer Drift Site
0.910	RU	VG					260.1	
0.121		TS					240.0	
0.051		SW					238.0	
0.081	PO	VG (1.5 m)	19	GR	L	H	248.3	Mouth of Surprise Canyon
0.031	SC						237.0	
0.031	SW							
0.151		VG					242.5	
0.081	PO	VG			L	H	248.3	Mouth of Surprise Canyon
0.141		SW				H	246.0	500 yards above Spencer
0.121	ED	VG			L	L	244.0	
0.031	ED				L	L	245.5	
0.011	ED				L	L	239.5	1\4 mi below Separation
0.031					H	L	243.5	
0.121					H	L	243.5	
0.131	SW	VG	16		H	L	271.0	flooded vg
0.061	SW	VG	16		H	L	269.0	flooded vg
0.081	PO	VG			H	L	248.3	Mouth of Surprise Canyon
0.121	ED		15.5		L	H	246.0	Above Mouth of Spencer
0.121	RU	BE	15.5		H	H	247.0	
0.061	VG	VG			H	H	269.0	
0.031	RU	VG	16		L	H	265.0	
0.101	LK	CO (2 m)	19.5	GR	H	L	280.0	Pearce Ferry
0.081	PO	VG	19	GR	H	L	248.3	
0.131	VG	VG			L	H	272.0	
0.011	VG	VG			L	H	266.3	
0.101	LK	CO	24	GR	L	L	285.0	God's Pocket
0.031	VG	VG	15		L	H	264.5	
0.011	VG	VG	15		H	H	266.3	
0.131	VG	VG	15		H	H	271.3	
0.081	PO	VG	22.5		L	L	248.3	Mouth of Surprise Canyon
0.121	ED		20		L	H	246.0	Mouth of Spencer Canyon
0.081	PO	VG	16.5		L	L	248.3	Mouth of Surprise Canyon
0.121	ED				L	H	246.0	Mouth of Spencer Canyon
0.121	ED	Alluvial fan (2-5 m)		GR,SI	H	H	246.0	Mouth of Spencer Canyon
0.081	PO	VG			L	H	248.3	Mouth of Surprise Canyon
0.061	VG	VG			H	H	269.0	

[1]Source: Unpublished data on-file at SWCA Environmental Consultants

5.3 Preliminary Evaluation of Razorback Sucker Habitat

In May 2009, Dave Speas (Reclamation) and Melissa Trammell (National Park Service) conducted a preliminary evaluation of potential razorback sucker habitat in lower Grand Canyon (Speas and Trammell 2009; see Appendix B).[1] They surveyed the habitat of the Colorado River by boat from Lava Falls (RM 179) to Lake Mead (RM 279). For each river mile in that reach, they recorded: (1) number and location of backwaters; (2) number of islands and side channels; (3) major habitat types as riffles, runs, eddies, spawning cobble, low-velocity habitat; (4) presence of cover (vegetation, turbidity); (5) water temperature; and (6) larval seine samples (collected opportunistically). Based on 1–4 above, they determined habitat complexity (i.e., the ability of the habitat to support multiple life stages of the razorback sucker) for each river mile. The quantitative criteria they used to define three habitat categories (complex, less complex, and poor) are shown in Table 16.

Table 16. Quantitative criteria defining quality of potential razorback sucker habitat in lower Grand Canyon (Speas and Trammell 2010).

Habitat Category	Backwaters / mi	Islands / mi	No. Habitat Types Present (mean)	Percent Vegetation Cover
Complex Habitat	0.50	0.62	2.2	0.29
Less complex Habitat	0.46	0.05	1.44	0.12
Poor habitat	0.19	0.08	1.00	0.04

Speas and Trammell (2010) designated the following reaches of the Colorado River in the lower Grand Canyon according to habitat complexity (Figure 26):

- Complex: RM 179–208, 220–223.
- Less complex: RM 209–219, 224–253.
- Poor habitat: RM 253–279.

The reach from RM 179–208 extends from Lava Falls rapid to just upstream of Granite Park. This 29-mi reach of river contains numerous side canyons, debris fans, eddy complexes, as well as a complexity of backwaters, islands, sand bars, and vegetation that could be suitable for different life stages of the razorback sucker. This complex habitat also occurs in a 3-mi reach from RM 220–223. Less complex habitat occurs in RM 209–219 and RM 224–253, where the channel is more canyon-bound with fewer debris fans and eddy complexes. The poorest habitat reported by Speas and Trammell (2009) occurs in RM 253–279, where the channel is lined by eroding sand banks that remain from deltaic deposits when Lake Mead was at a higher elevation. It should be noted that this reach also has a large cobble/gravel bar at the mouth of Salt Creek which is considered a potential spawning site.

[1] We wish to thank Dave Speas and Melissa Trammel for providing the information regarding their 2009 survey as presented in this section. The results shown here are preliminary and should be understood as such.

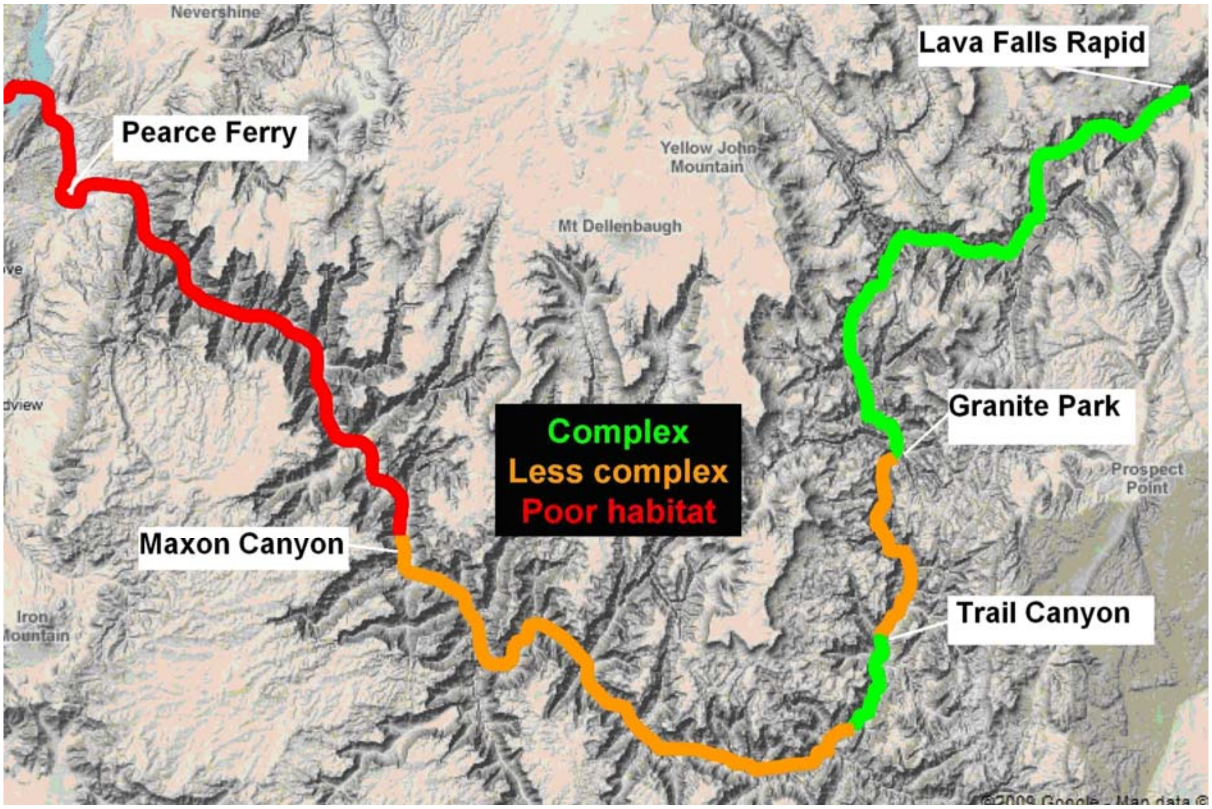

Figure 26. Complex, less complex, and poor potential habitat of razorback sucker in the Colorado River in lower Grand Canyon, RM 179–279. Figure from Speas and Trammell (2010).

Speas and Trammell (2009) also collected water temperature data during the May 2009 survey. Temperature ranged from a low of about 15.5°C at RM 179 to 18.5°C at RM 279 (Figure 27).

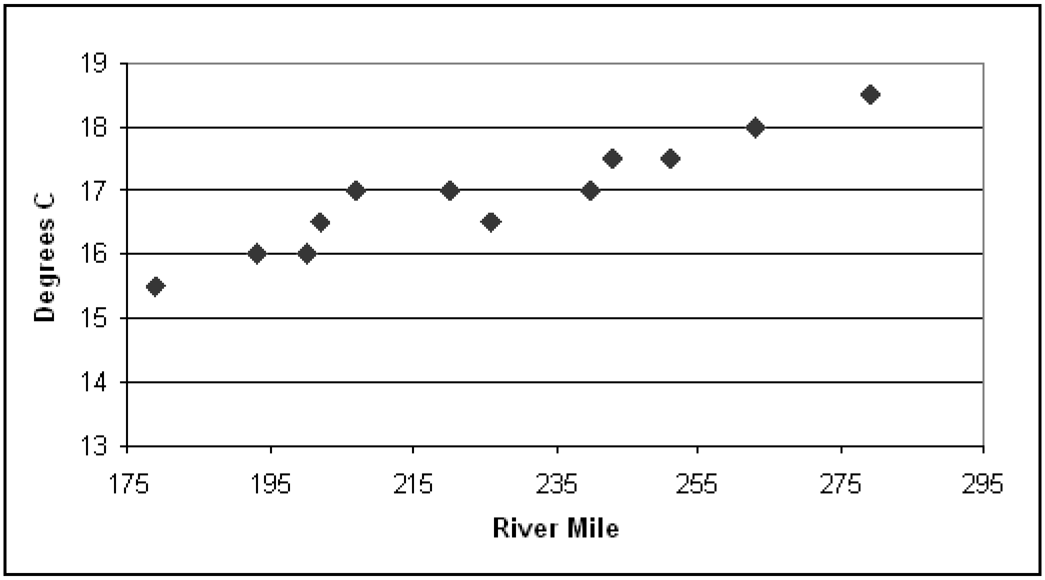

Figure 27. Water temperature data, RM 179–279, May 2009. Data from Speas and Trammell (2010).

Additional water temperature data gathered at GCMRC gauges are presented below (GCMRC data online at http://www.gcmrc.gov/products/otherdata/gcmrc.aspx). Three gauges are located within the lower Grand Canyon: RM 194 (194 Mile Canyon), RM 226 (Diamond Creek confluence), and RM 246 (Spencer Canyon confluence). Figure 28 shows the highest and lowest temperatures recorded at each gauge during January through September for the last full year of record: 2004 for RM 194 and 2009 for RM 226 and RM 246. Ideal spawning temperature for the razorback sucker is 15°C (range of 10–22°C) and ideal hatching temperature is 20°C (range of 10–30°C) (USFWS 2002) as displayed on each hydrograph. These figures show that ideal spawning temperature is reached about April, but a suitable range of hatching temperatures is not reached until May; temperatures shown are main channel temperatures and do not account for nearshore or sheltered habitats with warmer temperatures.

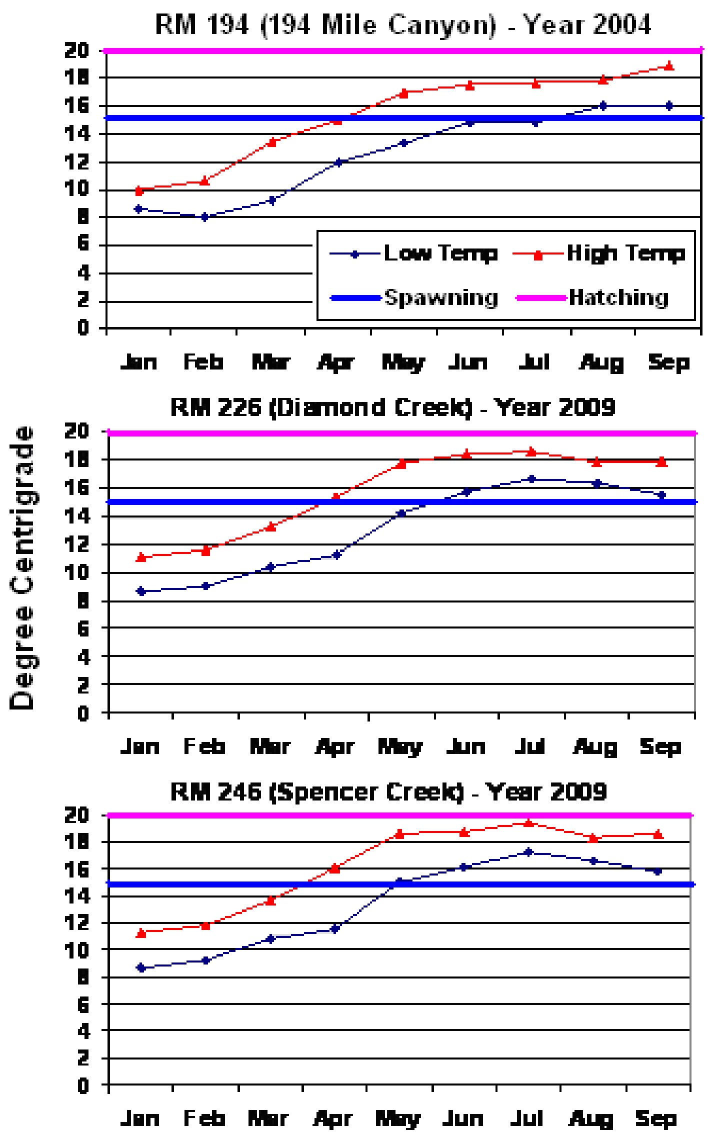

Figure 28. High and low water temperatures at RM 194 (Year 2004), RM 226 (Year 2009), and RM 246 (Year 2009) for the months January–September (GCMRC data). Ideal spawning temperature for the razorback sucker is 15°C (10–22°C) and ideal hatching temperature is 20°C (10–30°C).

5.4 Status of Razorback Sucker Population in Lake Mead

The largest populations of the razorback sucker are currently found in Lake Mohave and Lake Mead of the Lower Colorado River Basin (USFWS 2002). The Lake Mead population appears to be the only population with continued and sustained recruitment (Albrecht et al. 2010b). Between 1996 and 2008, a total of 517 individual adult and subadult razorback suckers were captured in Lake Mead, including 218 at Las Vegas Bay, 248 at Echo Bay, and 51 near the Muddy/Virgin River inflow areas (Figure 29).

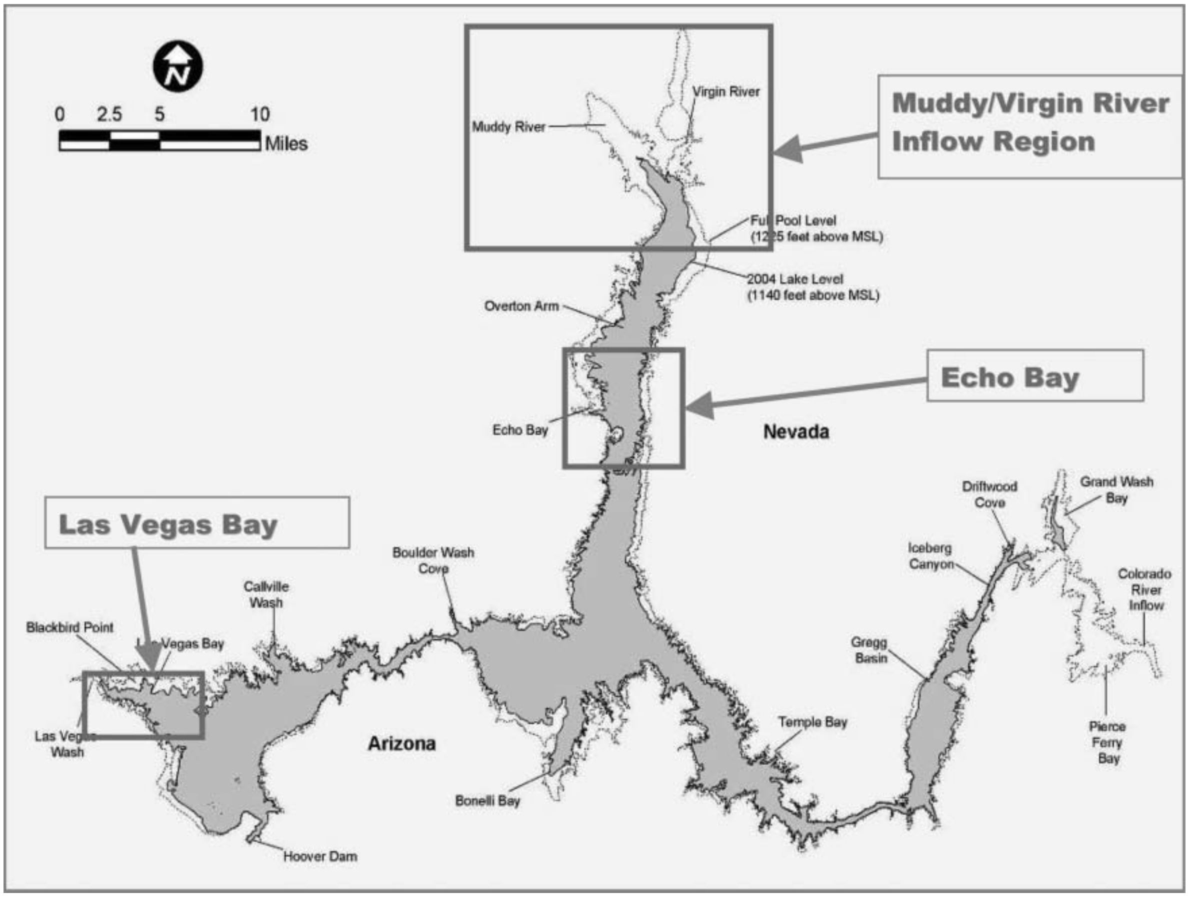

Figure 29. Lake Mead and locations of the razorback sucker populations in relationship to the Colorado River inflow at right of map. Figure from Albrecht et al. (2010b).

Mark-recapture population estimates of the razorback sucker were computed for Las Vegas Bay and Echo Bay for 1996–2007 using the Chao M_h estimator (Albrecht et al. 2008a; Figure 30). The population in Las Vegas Bay has ranged from a low of 52 individuals (95% CI = 18–272) for the period 2003–05, to a high of 310 (95% CI = 108–1,104) for the period 2002–04. The latest estimate is 271 (95% CI = 113–793) for the period 2005–07. The population in Echo Bay has ranged from a low of 39 individuals (95% CI = 25–89) for the period 2003–05, to a high of 142 (95% CI = 97–242) for the latest period, 2005–07. The sum of estimates for the two bays for each of the 11 periods range from a low of 91 individuals for 2003–05, to a high of 413 for the latest period, 2005–07.

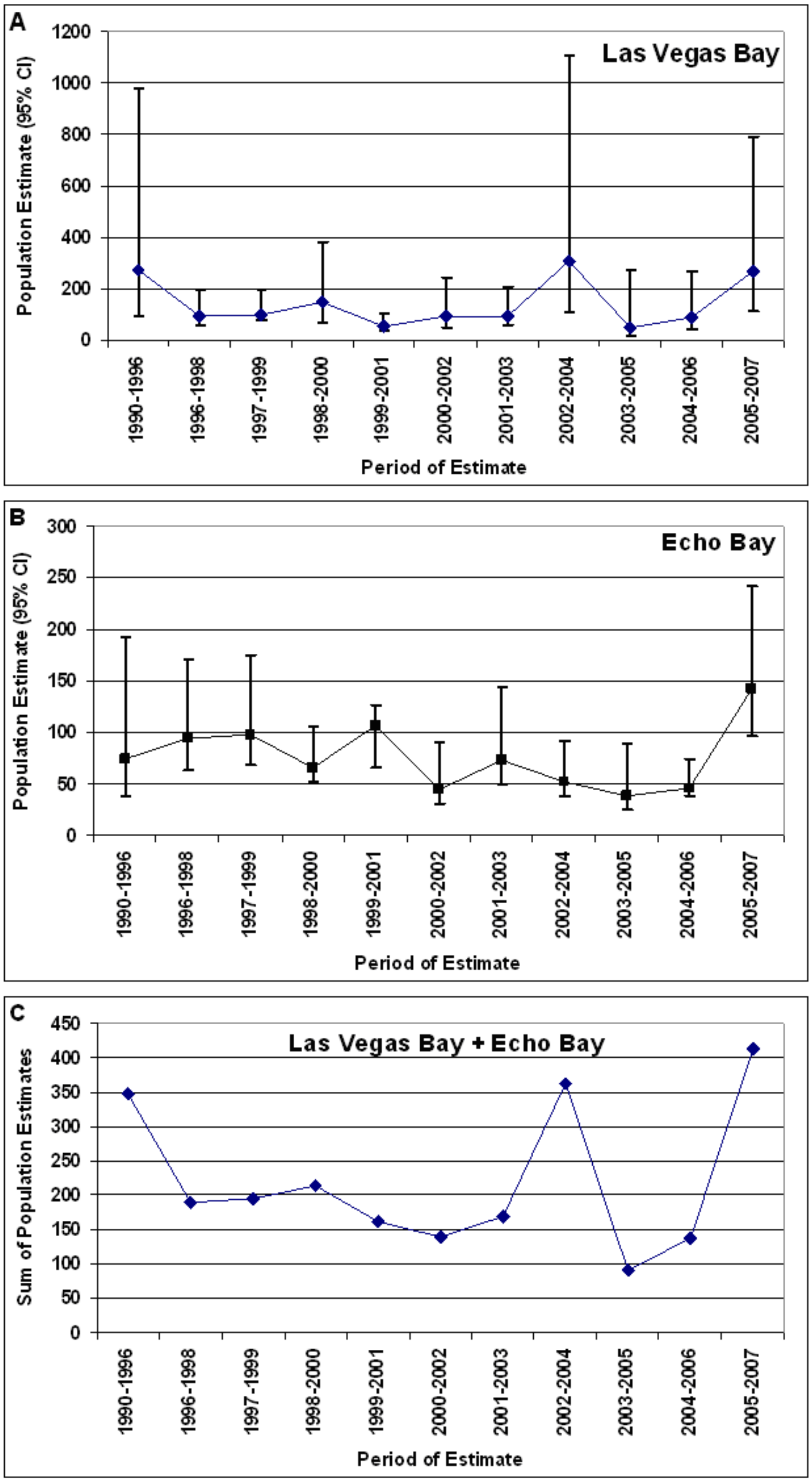

Figure 30. Population estimates (95% confidence intervals, CI) of the razorback sucker in (A) Las Vegas Bay, (B) Echo Bay, and (C) Las Vegas Bay + Echo Bay for 1996–2007. Data from Albrecht et al. (2008a) for the Chao Mh estimator.

From 1997 to 2007, a total of 12,607 larval razorback suckers were captured in Lake Mead, including 2,410 in Las Vegas Bay; 10,113 in Echo Bay; 47 in the Muddy River/Virgin River inflow area; 33 in the Colorado River inflow area (sampled from 1998 to 2004); and 4 in other locations (Albrecht et al. 2008a). The dates that larvae were first found in each of the four areas spanned from early February to late April, including February 5 to April 5 in Las Vegas Bay; February 22 to April 20 in Echo Bay; March 2 to April 12 in the Muddy River/Virgin River inflow; and April 29 for the Colorado River inflow.

The 33 larvae found in the Colorado River inflow area were caught on April 29 each in 2000 (11 larvae) and 2001 (22 larvae). These newly-hatched fish were captured between Iceberg Canyon and Grand Wash Bay, about 8 mi downstream from Pearce Ferry (Albrecht et al. 2008a; Figure 31). During the 2002 and 2003 spawning periods, no larval razorback suckers were captured in this area. This spawning site was either not used in 2002–2003, or spawning took place outside of the sampling area. Physical and chemical changes in spawning sites resulting from lake elevation changes may be responsible for the apparent inconsistent use of these sites in the Colorado River inflow region, as in other sites on Lake Mead described above.

In spring of 2010, seven larval razorback suckers were captured in the Gregg Basin region of the Colorado River inflow (Figure 31), as well as one larval flannelmouth sucker and four larval fish thought to be either flannelmouth sucker or hybrid flannelmouth x razorback sucker (Albrecht et al. 2010a). All larvae were captured April 13–14, 2010 at water temperatures of 14–16°C. Although catch rate was low, the identification of larval razorback suckers in the Colorado River inflow, as well as concurrent locations of radio-tagged fish and adults in spawning condition, provided compelling evidence of successful spawning in 2010. Spawning is believed to have occurred on rock and gravel points between North Bay and Devil's Cove, in the lake interface about 10 mi downstream of Pearce Ferry.

Albrecht et al. (2010a) reported that trammel netting in the inflow area on April 20, 2010, yielded three male razorback suckers expressing milt, which helped confirm spawning activities. Two of these individuals were 6 years old and one was 11 years old. Altogether, four razorback x flannelmouth sucker hybrids, and 52 flannelmouth suckers were captured with trammel nets in 2010 in the Colorado River inflow. Sonic-tagged razorback sucker released near the Colorado River inflow in 2010 used the riverine habitat and inflow region as far upstream as the mouth of Devil's Cove, about 8 mi downstream of Pearce Ferry. Individual sonic-tagged fish have been tracked as far upstream as the base of the newly formed "Pearce Ferry rapid" (about 1 mi downstream of Pearce Ferry; see Figure 31), but the fish have not ascended this rapid, suggesting that it is an impediment to upstream fish movement. Razorback suckers have not been caught recently upstream of Pearce Ferry or in the lower Grand Canyon.

Ongoing studies of the Lake Mead razorback sucker population suggest that changes in lake elevation are responsible for the apparent and sudden recruitment in the late 1970s (Albrecht et al. 2010b). The population in Lake Mead is believed to have originated from resident or transient individuals that became trapped in the reservoir as it was filling from the 1930s to about 1963. The lake was drawn down approximately 100 ft in the mid-1960s as Lake Powell filled, but from about 1964 to 1987, Lake Mead filled slowly with small annual fluctuations that reflected seasonal inflow and releases to satisfy downstream water demand and delivery (Figure 32).

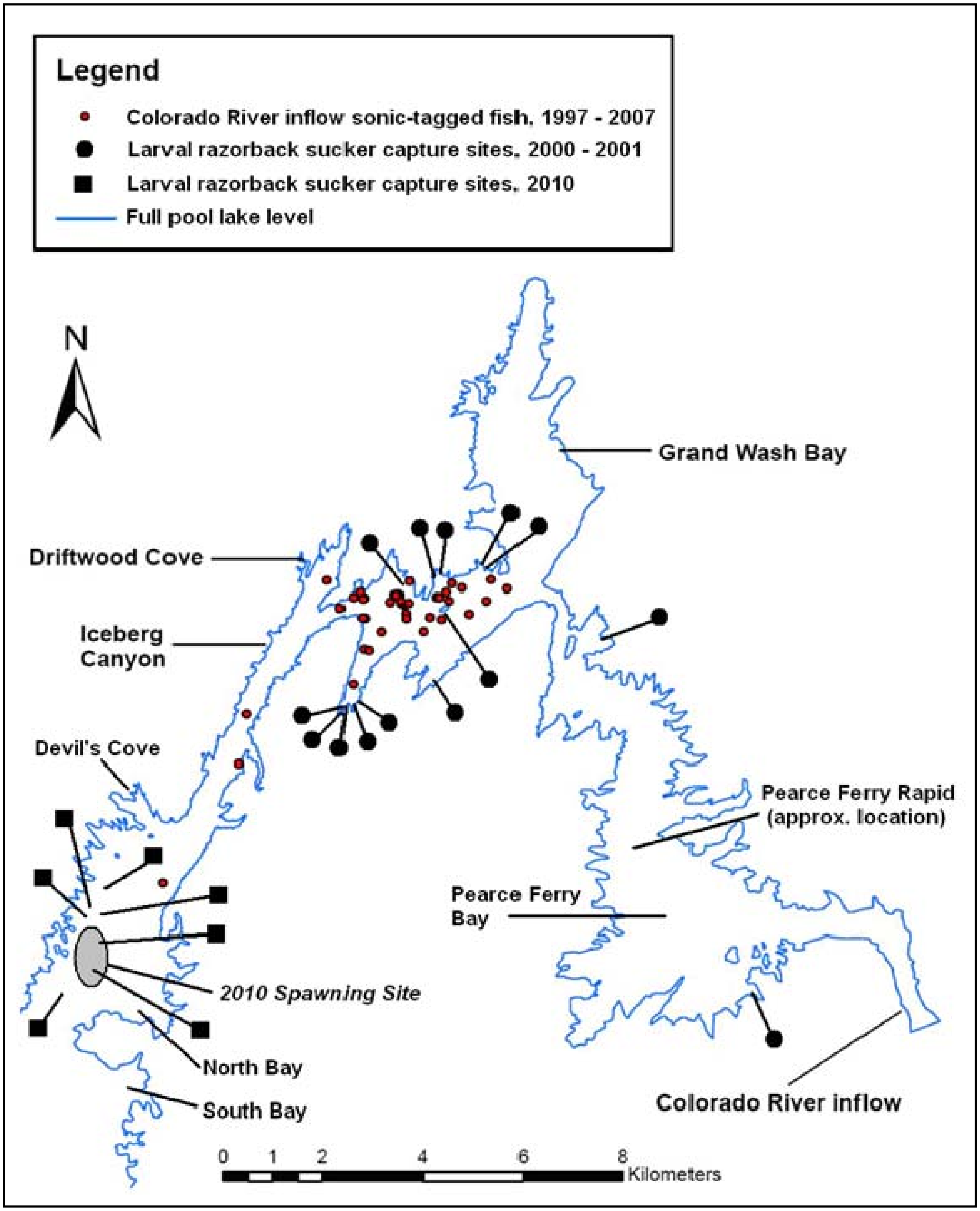

Figure 31. Locations of sonic-tagged razorback suckers, 1997–2007, and larval capture sites, 2000, 2001, and 2010, in the Colorado River inflow and Gregg Basin area of Lake Mead. Figure modified from Albrecht et al. (2008a, 2010a).

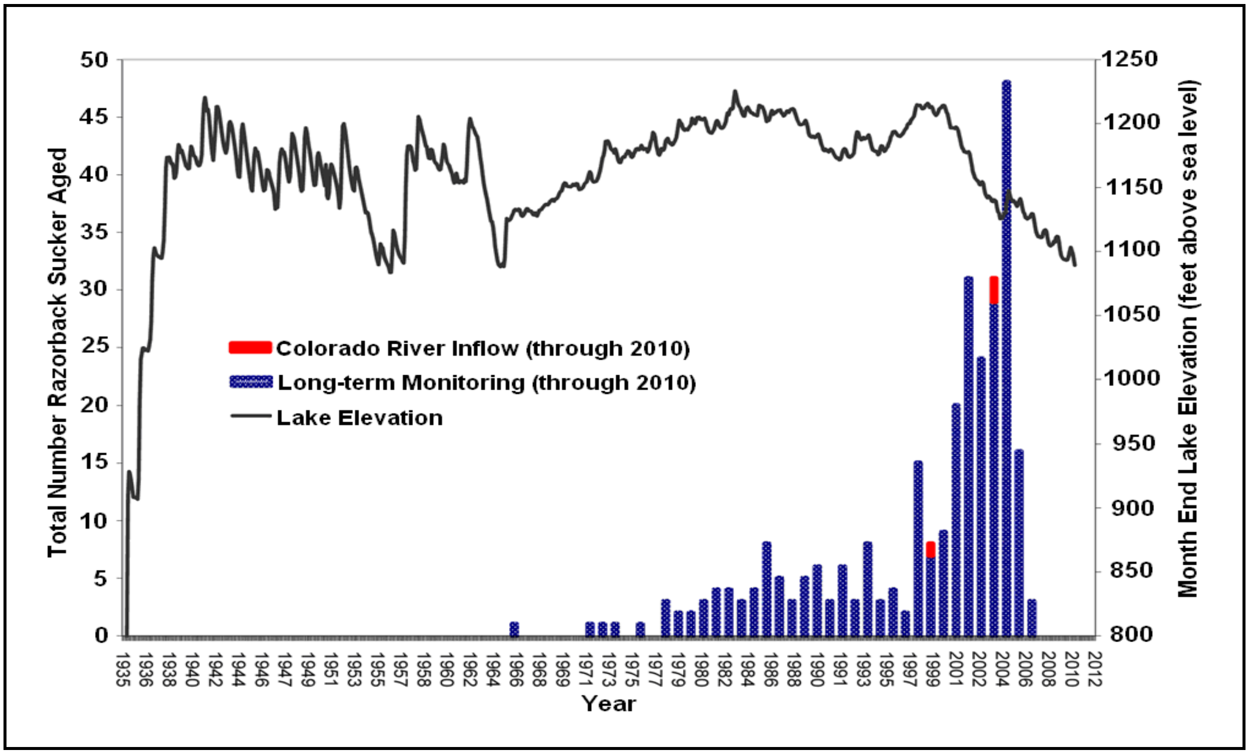

Figure 32. Lake Mead elevation from January 1935 to June 2010 with the number of razorback suckers that were hatched each year, based on back-calculated ages as determined from fin ray sections. Red bars depict razorback sucker captured at the Colorado River inflow area in 2010 and dark bars represent numbers of fish from the cumulative long-term monitoring and aging efforts. Figure from Albrecht et al. (2010a).

Expansive deltaic deposits formed at the inflows during high lake elevations, and these became populated with dense stands of tamarisk, willows, cottonwoods, and other riparian plants that got regularly watered with the fluctuating reservoir levels. A drawdown in the early 1990s allowed further downslope encroachment of vegetation along the lake shorelines, and much of the riparian vegetation at higher elevations became desiccated and died. The low-lying vegetation was inundated as the lake rose in the late 1990s, providing cover in coves and other littoral habitats for young razorback suckers. It is hypothesized that the reinundation of this low-lying vegetation provided the cover and nutrients that allowed the young suckers to escape predators and provided an abundance of food.

The level of Lake Mead has continued to drop since about 2000 because of continuing regional drought, but it appears that sufficient vegetation remains to provide cover for the young suckers. Investigators are finding that both turbidity and vegetation are substantially more abundant in Las Vegas Bay and Echo Bay than in other coves, suggesting that both cover factors play a role in recruitment (Albrecht et al. 2010b). Recent aging of razorback suckers from Lake Mead shows that recruitment pulses have occurred when shoreline vegetative cover was available—but recruitment has also occurred at low lake conditions when vegetative cover was limited but turbidity was high. These findings suggest that the best chances for successful reproduction and recruitment by the razorback sucker is in areas that provide vegetative cover and turbidity, such as the large river inflows including the Colorado River.

6.0 HABITAT SUITABILITY OF LOWER GRAND CANYON

6.1 Overview of Habitat Use

This document provides an assimilation of habitat information and data for various life stages of the razorback sucker from throughout its range in the Colorado River System. Altogether, 84 scientific reports and publications were used as sources for this habitat information (Table 17). Information gleaned from these sources is presented in sections 2.0, 3.0, and 4.0 of this report.

The information gleaned from these reports and publications is used in this section to help evaluate the suitability of habitat for the razorback sucker in the lower Grand Canyon. This evaluation begins with a comparative analysis of system-wide quantitative information and the limited information available for the lower Grand Canyon. Quantitative data on depth, velocity, substrate, and mesohabitat were available from seven sources highlighted in Table 17. These are provided in Appendix A in their original forms as “habitat suitability criteria” and data were extracted from each to derive a summary of frequency information for depth, velocity, and substrate (i.e., microhabitat) used by adult razorback suckers system-wide (Figure 33).

Microhabitat data were not available for the lower Grand Canyon and a comparison with existing habitat was not possible. However, mesohabitat data were available for comparisons among radio-tagged adult razorback suckers in lower Grand Canyon (SWCA unpublished data), adults from all rivers (see highlighted citations in Table 17), and mesohabitat availability (Speas and Trammell 2010) (Figure 34). A direct comparison among these three datasets is not entirely possible because of different criteria used to classify mesohabitat types and an apparent inconsistent use of terminology for habitat types.

Visual examination of these three datasets shows that radio-tagged adult razorback suckers in the lower Grand Canyon used eddies, pools, runs, slackwaters, and vegetated shorelines, which is a similar suites of mesohabitats used throughout the species range. Speas and Trammell (2009) found that the most common primary mesohabitats available in lower Grand Canyon were runs, riffles, eddies, and rapids; whereas backwaters were less common.

A Chi^2 association test was not possible for these datasets because of the large numbers of zeros in mesohabitat categories. A Kolmogorov-Smirnov test was run to determine if the three samples had the same distribution. Two-tailed tests revealed that comparisons among all three distributions (radiotelemetry, all rivers, and availability) were significantly different ($p < 0.05$). In other words, despite apparent similarities among distributions, the degree of similarity was significantly different. Given the paucity of habitat data for the lower Grand Canyon, these data and analysis are considered preliminary and inconclusive.

Table 17. A list of citations used as sources for habitat information for the razorback sucker. Sources of habitat suitability criteria are highlighted in gray and the criteria provided in Appendix A, and summarized for microhabitat in Figures 20–22 and for mesohabitat in Figures 33–34. Detailed citations are provided in the Literature Cited section of this report.

Number	Citation	Number	Citation
1	Albrecht et al. 2008a	43	McAda and Seethaler 1975
2	Albrecht et al. 2008b	44	McAda and Wydoski 1980
3	Albrecht et al. 2009	45	Medel-Ulmer 1983
4	Albrecht et al. 2010a	46	Miller et al. 1982
5	Albrecht et al. 2010b	47	Minckley 1983
6	Bestgen 1990	48	Minckley et al. 1991
7	Bestgen and Haines 2010	49	Modde 1996
8	Bestgen et al. 2002	50	Modde 1997
9	Bezzerides et al. 2002	51	Modde and Wick 1997
10	Black and Bulkley 1985	52	Modde and Irving 1998
11	Bozek et al. 1984	53	Modde et al. 1999
12	Bozek et al. 1990	54	Mueller 1989
13	Bozek et al. 1991	55	Mueller et al. 1982
14	Bradford and Vlach 1995	56	Mueller et al. 1985
15	Bradford and Gurtin 2000	57	Mueller et al. 2005
16	Bulkley and Pimentel 1983	58	Muth et al. 1998
17	Bulkley et al. 1981	59	Osmundson and Kaeding 1989a
18	Burdick 2002	60	Osmundson and Kaeding 1991
19	Burdick 2003	61	Osmundson and Seal 2009
20	Burdick and Bonar 1997	62	Pacey and Marsh 1998
21	Chart et al. 1999	63	Ryden 2000
22	Christopherson et al. 2004	64	Ryden 2001
23	Clarkson et al. 1993	65	Schooley et al. 2008
24	Douglas 1952	66	Seethaler et al. 1979
25	Ferriole 1988	67	Severson et al. 1990
26	Guterrmuth et al. 1994	68	Sigler and Miller 1963
27	Gurtin and Bradford 2000	69	Simon 1951
28	Haines 1995	70	Toney 1974
29	Hamman 1985	71	Tyus 1987
30	Holden 1977	72	Tyus and Karp 1989
31	Holden and Masslich 1997	73	Tyus and Karp 1990
32	Holden and Stalnaker 1975	74	Tyus et al. 1981
33	Inslee 1981	75	Tyus et al. 1982
34	Jonez and Sumner 1954	76	Valdez and Masslich 1989
35	Kegerries et al. 2009	77	Valdez et al. 1982
36	Kidd 1977	78	Valdez et al. 1985
37	Kretschmann and Leslie 2006	79	Valdez et al. 1987
38	Loudermilk 1981	80	Valentine 1981
39	Marsh 1985	81	Vanicek 1967
40	Marsh and Minckley 1989	82	Wick et al. 1982
41	Marsh and Papoulias 1989	83	Wydoski and Mueller 2006
42	Marsh and Pisano 1985	84	Wydoski and Wick 1998

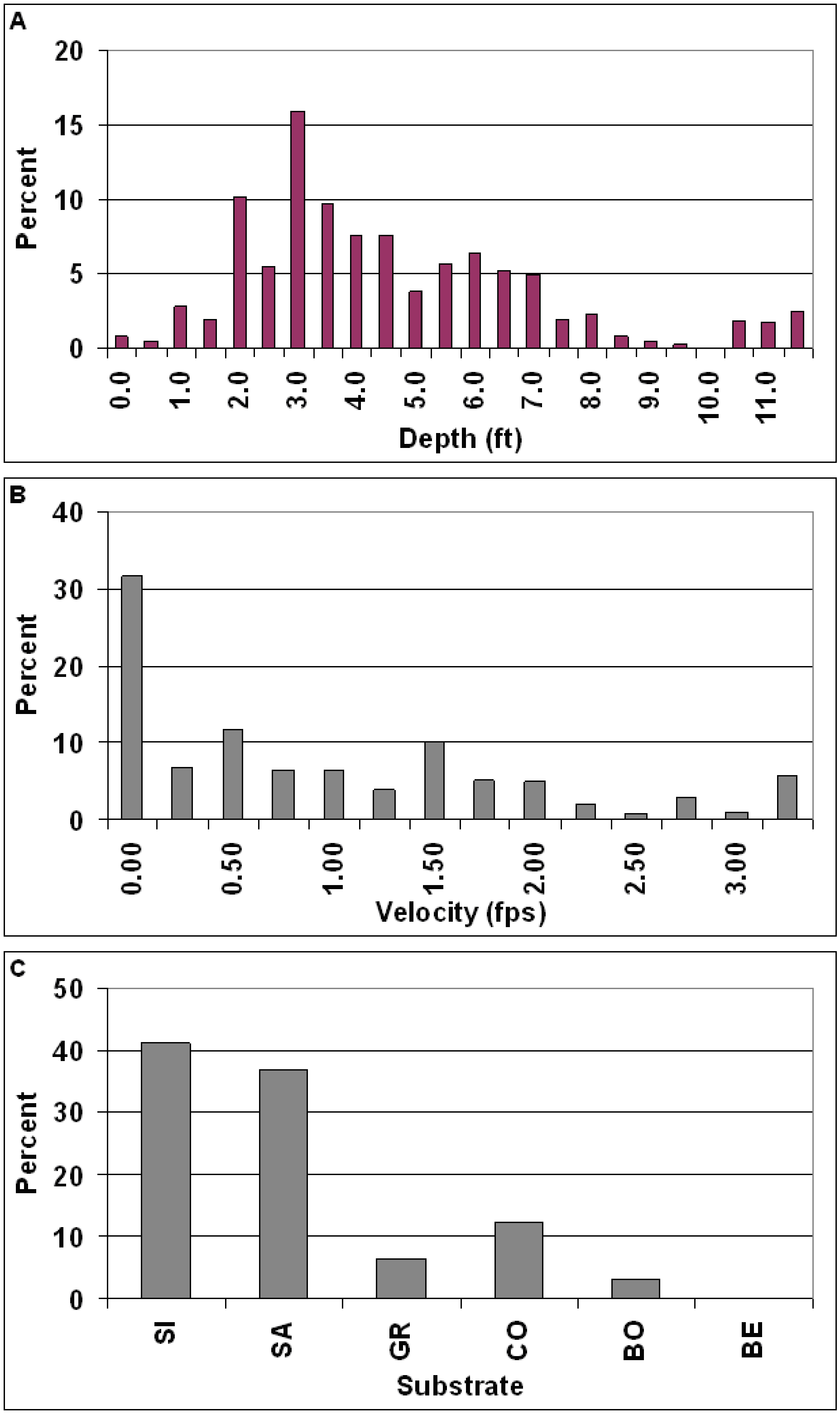

Figure 33. Summary of all data for (A) depth, (B) velocity, and (C) substrate used by adult razorback suckers in rivers. Data sources are highlighted in Table 17. See Figure 22 caption for substrate codes.

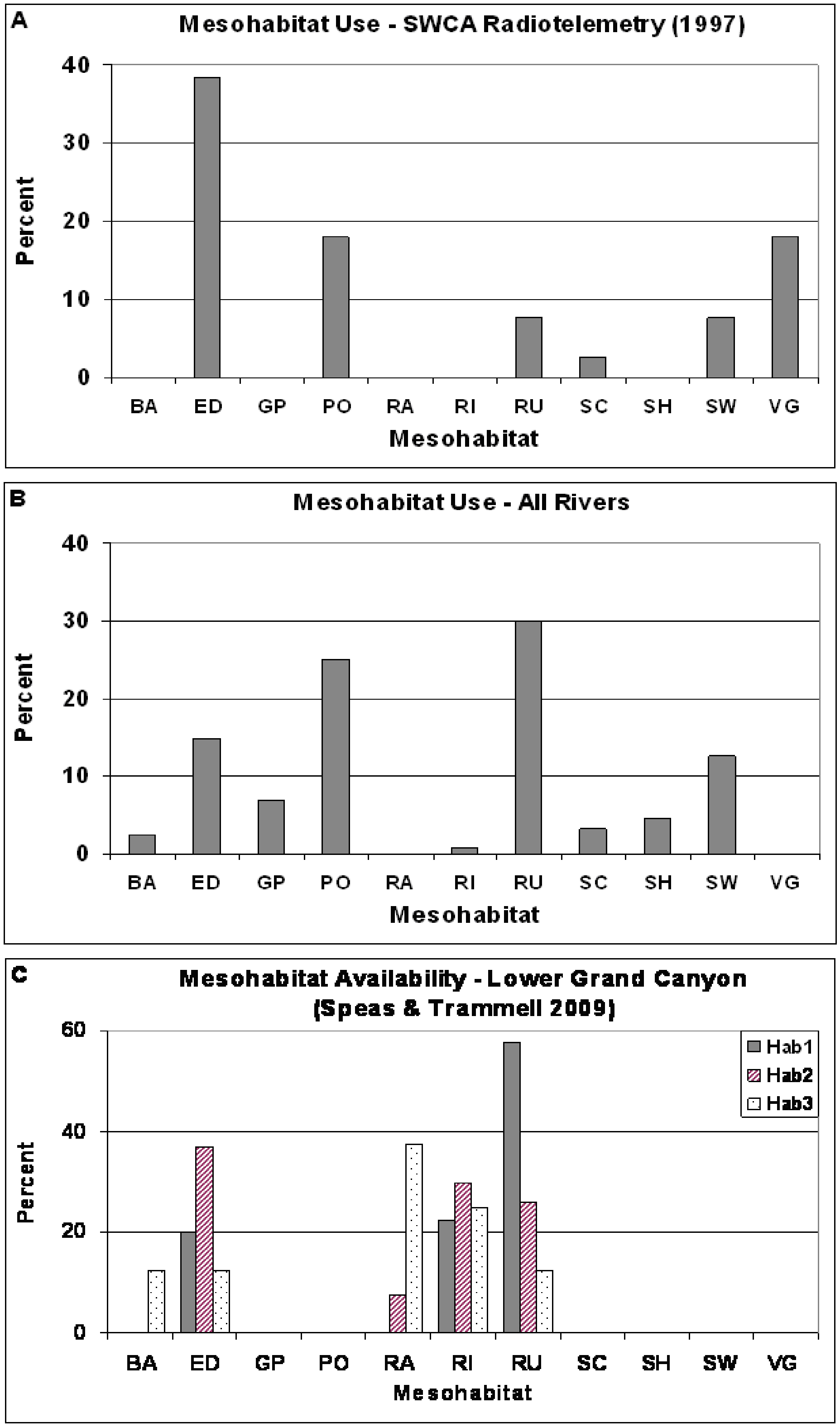

Figure 34. Mesohabitat use by (A) radio-tagged adult razorback suckers in lower Grand Canyon, and (B) adult razorback suckers from all rivers, compared to (C) mesohabitat availability in lower Grand Canyon. See Figure 19 caption for mesohabitat codes.

6.2 Comparison of Habitat Profiles

This section uses the information assimilated on habitat use by the razorback sucker to develop a profile of habitat for the species and draws a qualitative comparison between habitat used and available habitat in the lower Grand Canyon. To clarify, the lower Grand Canyon is considered to be the Colorado River from the base of Lava Falls rapid (RM 180) to Pearce Ferry (RM 280). This comparison cannot be done without including an assessment of the potential role of Lake Mead and the Colorado River inflow below Pearce Ferry.

6.2.1 Spawning and Larval Drift

Table 18 provides a profile of habitat used by various life stages of the razorback sucker and qualitatively compares habitat attributes with available habitat in lower Grand Canyon and the Colorado River inflow to Lake Mead. The razorback sucker in a riverine setting consistently uses cobble/gravel bars for spawning. These bars may be located at the base of canyons, such as Split Mountain Canyon or Desolation Canyon on the Green River, or they may be located in complex channel areas such as “The Mixer” on the San Juan River. In a reservoir setting, razorback suckers use rocky shorelines and shoals for spawning, such as the shorelines of Lakes Mohave and Mead.

Large cobble/gravel bars similar in appearance to those used for river spawning are present at tributary inflows and canyon mouths in lower Grand Canyon, including Diamond Creek (RM 226), Spencer Canyon (RM 246), and Surprise Canyon (RM 248.3) (Figures 35 and 36). Rocky shorelines are also present in the Colorado River inflow, where razorback suckers are believed to have spawned in 2010.

Razorback suckers broadcast and fertilize their eggs over cobble/gravel bars, whereupon the eggs become semi-adhesive and adhere to the rocks in crevices and interstitial spaces. The eggs incubate for 6–7 days and the embryos emerge as tiny larvae (about 0.7 in long) without fins or a functional mouth. Newly emerged larvae are typically swept downstream by river currents or washed by wave action in reservoirs, but they must quickly find sheltered productive nursery areas for feeding and shelter from predators. The larvae rely on a small yolk sac for nourishment, but it is quickly absorbed and they must feed within 8–19 days of hatching or they will starve.

Unimpeded and secure drift corridors are essential to larval survival. Many larvae drift at night or under the cover of turbidity to escape predation. Because the larvae lack well-developed fins, they are reliant on river currents to become carried into a productive nursery area. Hence, the location of nursery areas a short distance downstream from spawning sites is vital to the species.

Although there are no floodplains in the lower Grand Canyon, there are numerous backwaters that are used by other native Colorado River suckers, and are similar to backwaters used by razorback sucker larvae in the San Juan River. Speas and Trammell (2009) counted 22 backwaters between RM 181 and RM 265 that could provide potential nursery habitat for larval razorback suckers. Additionally, the Colorado River inflow could provide substantial nursery habitat, depending on lake elevation.

Table 18. Profile of habitat used by various life stages of the razorback sucker compared to available habitat in lower Grand Canyon.

Life Stage	Habitat Profile	Habitat in Lower Grand Canyon
Spawning and Larval Drift	• In Rivers: Cobble/gravel bars • In Reservoirs: Rock shoals	• In Lower River: Cobble/gravel bars in river at canyon mouths (Spencer, Salt) • In Lake Mead: Rock shoals in upper Gregg Basin
Larval Nursing, and Rearing	• In Green, Colorado Rivers: Seasonally inundated floodplains • In San Juan River: backwaters and embayments • In Reservoirs: Rock shoals with vegetative cover and turbidity from river inflow	• In Lower River: No large floodplains in river, but numerous large backwaters used by other native suckers • In Lake Mead: Rock shoals with vegetative cover and turbidity from river inflow
Juvenile and Adult Maintenance and Movement	• In Rivers: low velocity eddies, pools, runs, backwaters, floodplains • In Reservoirs: shorelines with rocky and vegetative cover	• In Lower River: Low velocity eddies, pools, runs, backwaters • In Lake Mead: shorelines with rocky and vegetative cover

If spawning was to occur at the three large cobble/gravel bars identified in the lower Grand Canyon (i.e., Diamond Creek, RM 225.6; Spencer Canyon, RM 246; and Surprise Canyon, RM 248.3), the distance that larvae would have to drift to reach potential nursery habitat in Pearce Ferry Bay (RM 280) would be 54.4, 34, and 31.7 mi, respectively (Figure 37). At an estimated average river speed of 2.5 mph, a passively drifting larva could reach Pearce Ferry Bay in about 21.8, 13.6, and 12.7 hr, respectively, which is presumably sufficient time to prevent starvation. As a comparison for larval drift, the distance from a known spawning bar to floodplains used as nurseries in the middle Green River ranges from about 6 to 60 mi, and the greatest distance from the uppermost bar in lower Grand Canyon (Diamond Creek) to the known spawning bar in the Colorado River inflow is 64 mi.

It is noted that of the 33 razorback sucker larvae found in the Colorado River inflow in 2000 and 2001, one was located in Pearce Ferry Bay. The origin of this fish is unknown, but at the time of collection, Pearce Ferry Bay was inundated by Lake Mead and it is possible that this larva was transported to that location by winds and water currents. It is unlikely that the fish was hatched from a local spawning event because there are no known cobble/gravel bars in the area and the river channel in and near Pearce Ferry Bay is part of the large eroding silt/sand delta of the Colorado River. It is also possible that this and other larvae originated from one of several bars in the lower Grand Canyon.

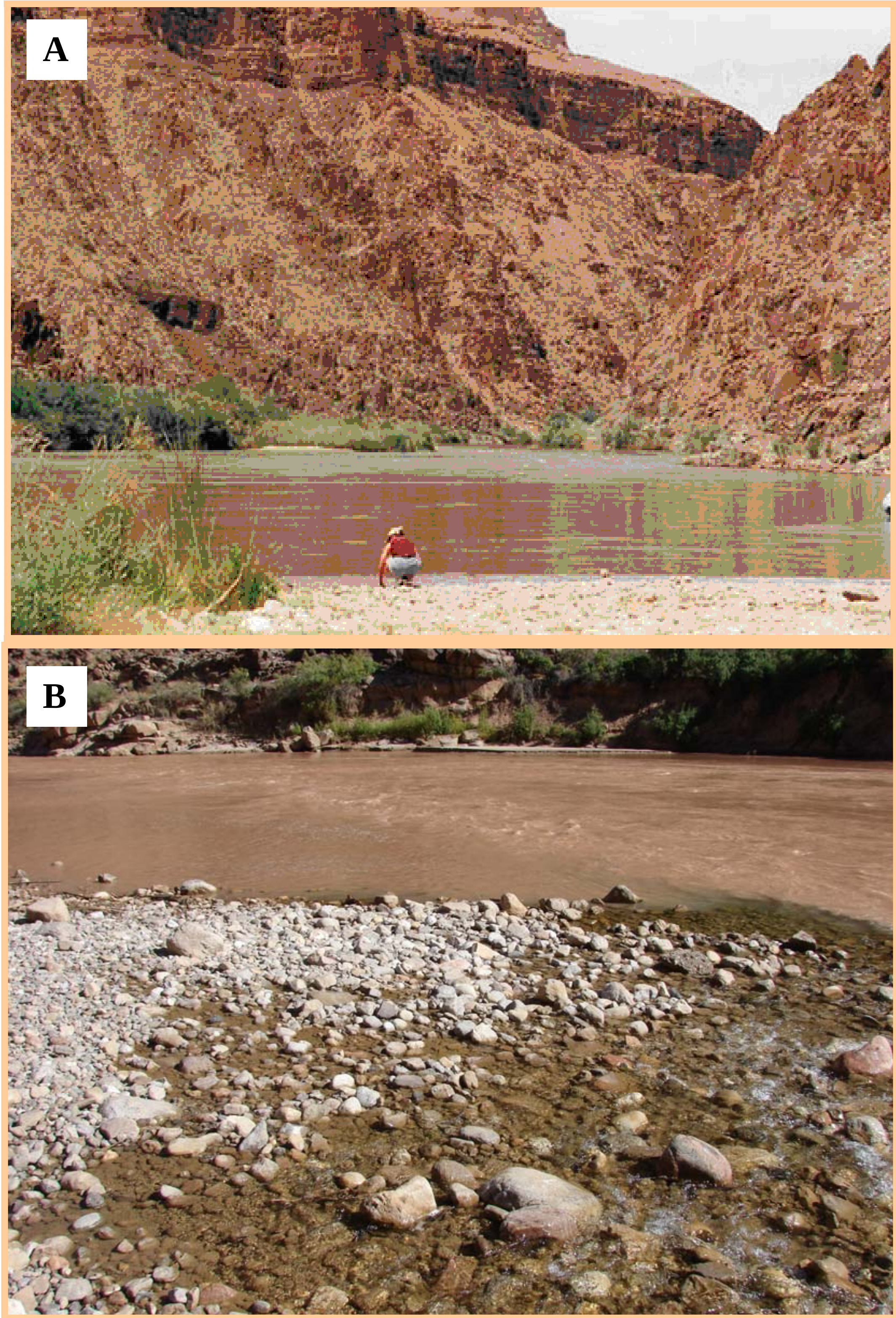

Figure 35. Photos of cobble/gravel bars at (A) Diamond Creek, and (B) Spencer Canyon in lower Grand Canyon. Photo of Diamond Creek courtesy of Hualapai Tribe. Photo of Spencer Canyon taken September 18, 2010 by C. McAda when flow of the Colorado River was 9,200–9,300 cfs.

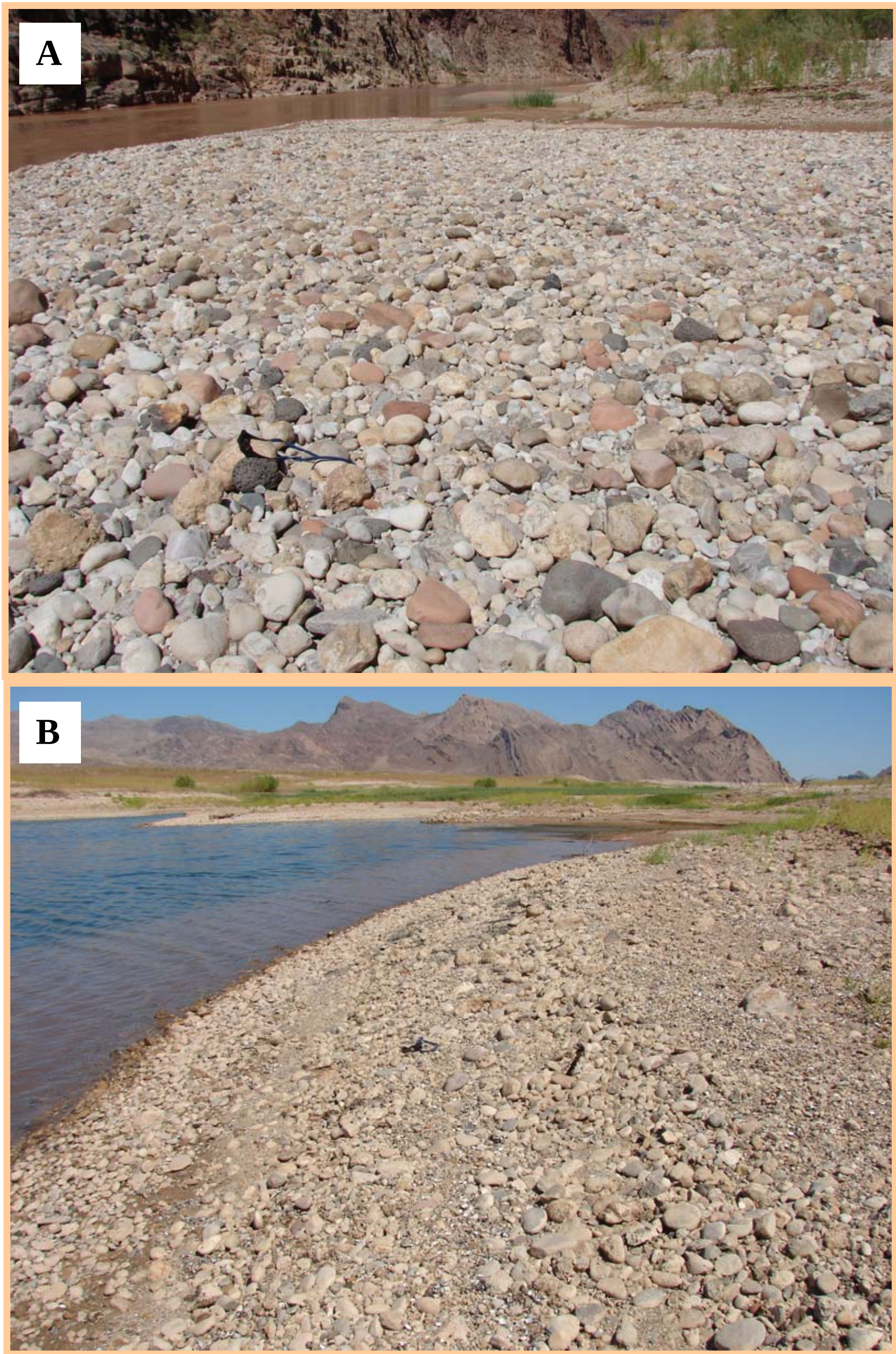

Figure 36. Photos of cobble/gravel bars (A) at Salt Creek in lower Grand Canyon, and (B) between Devil's Cove and North Bay near known spawning area in the Colorado River inflow. Flow of the Colorado River was 9,200–9,300 cfs. Photos taken September 18–19, 2010 by C. McAda.

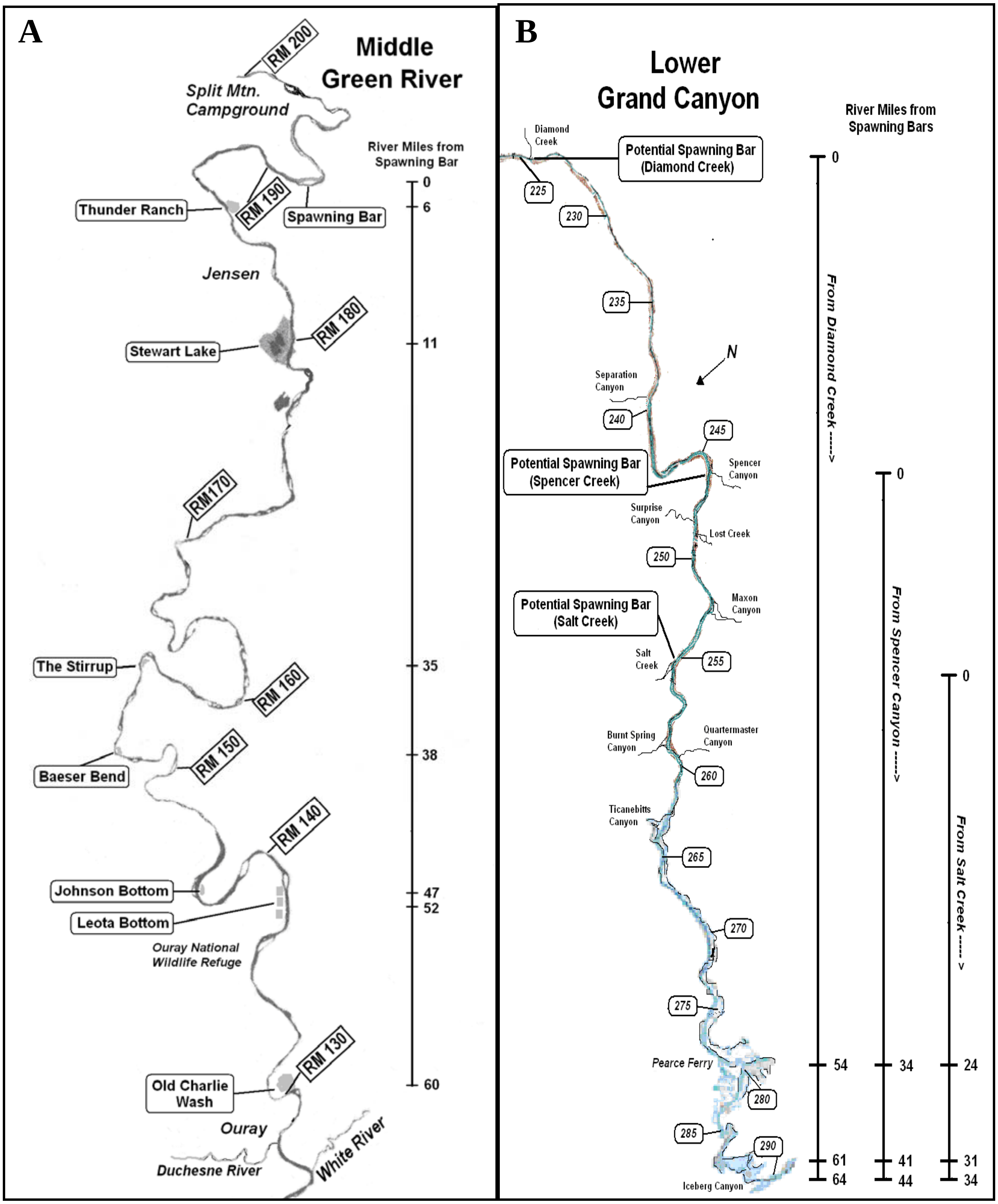

Figure 37. Comparison of distances from (A) a known spawning bar to nursery floodplains in the middle Green River, and (B) three potential spawning bars in lower Grand Canyon to known nursery areas in the Colorado River inflow to Lake Mead. Distances on vertical bars are approximate distances along the river channel. River miles are shown as blocked numbers on each map.

6.2.2 *Larval Nursing and Rearing*

Larval razorback suckers in a riverine setting typically use large riverside floodplains as nurseries. These floodplains become connected and inundated with high spring flows that coincide with spawning events. Floodplains used as nurseries include the areas on the Green River between Split Mountain and Desolation Canyon, and in the area of Grand Junction in the Colorado River. Where natural floodplains are absent or lacking, the larvae nurse in artificial features that function like floodplains, including gravel pits, such as the Colorado River and the Gunnison River near Grand Junction. Few larval razorback suckers are found in backwaters of these rivers because this habitat feature forms at lower river flows. In steep-gradient rivers where floodplains are lacking, such as the San Juan River, larval razorback suckers use backwaters or small embayments. It should also be noted that larvae hatched in the San Juan River are also found in the Lake Powell inflow, where investigations continue to determine if these fish are surviving and recruiting back to the river population.

In a reservoir setting, emerging larvae are subject to wave action and wind, but may be exposed to high levels of predation because of high water clarity, a lack of cover, and large numbers of predators. Recent investigations in Lake Mead have found larval razorback suckers along vegetated shorelines and in areas with moderate to high turbidity, such as river inflows. These findings suggest that cover in the form of vegetation and/or turbidity helps the larvae find shelter from predators and enhances their chances of survival.

Floodplains, such as used in the Green and Colorado rivers as nurseries by larval razorback suckers, are absent from the lower Grand Canyon. Large embayments occur at canyon mouths that could serve as floodplains if connected to the main channel at locations such as Surprise Canyon, Lost Creek, Burnt Spring Canyon, and Ticanebitts Canyon. These embayments were formed when Lake Mead was at a higher elevation, but the receding lake levels deposited large sand/silt berms that blocked the mouths of these canyons. Some of these isolated embayments retain water from up-canyon seepage or from subterranean river connection, but reconnecting these features is not reasonable because of the remote location and the uncertainty of their value as nurseries in this setting. Isolated embayments also exist at Grand Wash Bay and Driftwood Cove (below Pearce Ferry), and numerous small, muddy, backwater-like indentations along the river's margins may provide ephermeral rearing habitat. The only features that could reliably function as nurseries for larvae in the lower Grand Canyon are small sandy backwaters and complex shorelines (Figure 38). Much of the shoreline in the Colorado River inflow is unstable sand bars, but past about Iceberg Canyon a more stable rocky habitat is available (Figure 39). Based on calculations provided in the previous subsection, potential spawning bars in the lower Grand Canyon are a sufficient distance from the Colorado River inflow to be reached by a drifting larva before starving.

Many investigators feel that the most important factor affecting survival of larval razorback suckers in nurseries is predation by nonnative fish species, as well as amphibians and insects. Predators clearly exist in the lower Grand Canyon and in the Colorado River inflow. No management action is available to minimize this predation, although the apparent history of razorback sucker recruitment in Lake Mead suggests that turbidity and vegetated shorelines help to enhance larval survival and recruitment (Albrecht et al. 2010b).

Figure 38. Photos of (A) sand backwater used by young native suckers, and (B) complex shoreline habitat with rocky and vegetated shoreline in lower Grand Canyon. Flow of the Colorado River was 9,200–9,300 cfs. Photos taken September 16, 2010 by C. McAda.

Figure 39. Photos of (A) eroding sand backs near Pearce Ferry, and (B) exposed Lake Mead shoreline and high band of vegetation used by razorback sucker larvae at higher lake levels. Flow of the Colorado River was 9,200–9,300 cfs. Photos taken September 19, 2010 by C. McAda.

6.2.3 Juvenile and Adult Maintenance and Movement

Large juvenile and adult razorback suckers in rivers use a variety of habitats generally characterized by low to moderate velocity, moderate to deep water, and a soft silt or sand substrate. The only time that adults consistently use swift, shallow water with a rocky substrate is during spawning, or during movements to and from spawning sites. Habitats typically used by juveniles and adults for maintenance include runs, pools, and eddies where the fish can maintain their position and feed on drifting or bottom organisms and detritus with little energy expenditure.

In a reservoir setting juveniles and adults also use a variety of habitats, but tend to stay near shorelines with rocky or vegetative cover or in areas with turbidity. These fish may move extensively in reservoirs and not necessarily for spawning.

The Colorado River in the lower Grand Canyon is a canyon-bound reach with a complex of habitat types potentially useable by subadult and adult razorback suckers (Figure 40A). There are no barriers to movement in this reach of the Colorado River except perhaps for a large rapid that formed in 2009 about 1 mi downstream from Pearce Ferry (Figure 40B). Radio-tagged fish from Lake Mead have been tracked to areas below this rapid, but none have been documented to ascend past this point. The water level at the rapid drops about 10 ft, and water velocities appear to be quite high. Possibly, this feature is at least a partial barrier to upstream movement of razorback suckers, although the single larvae collected in Pearce Ferry Bay indicates that at least some fish have been upstream of this rapid. Because the river channel is still eroding the deltaic deposits in the Colorado River inflow to Lake Mead, the appearance of this rapid is likely to change over time. Hence, although the habitat in the lower Grand Canyon appears suitable for large juvenile and adult razorback suckers, movement of fish from the Lake Mead population may currently be impeded by this rapid.

The habitat in the Colorado River inflow downstream of the Pearce Ferry Rapid also appears suitable (Figure 41A) and has recently been used by razorback suckers, including fish moving into the area from the other populations at Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River inflow. The suitability of the habitat in this area evidently varies with lake elevation, but the lake level for optimal habitat is not presently known.

The recent invasion of the nonnative quagga mussel (*Dreissena rostriformis bugensis*) into Lake Mead (Figure 41B) may have adverse consequences on the aquatic ecosystem, especially at the primary producer level. The quagga mussel is a filter feeder and its rapid rate of population increase can result in large amounts of nutrients being filtered from the water column and a collapse of the primary producers, including the phytoplankton and zooplankton communities. Because young razorback suckers rely on zooplankton for food, the quagga mussel could have a detrimental effect on their food supply in Lake Mead.

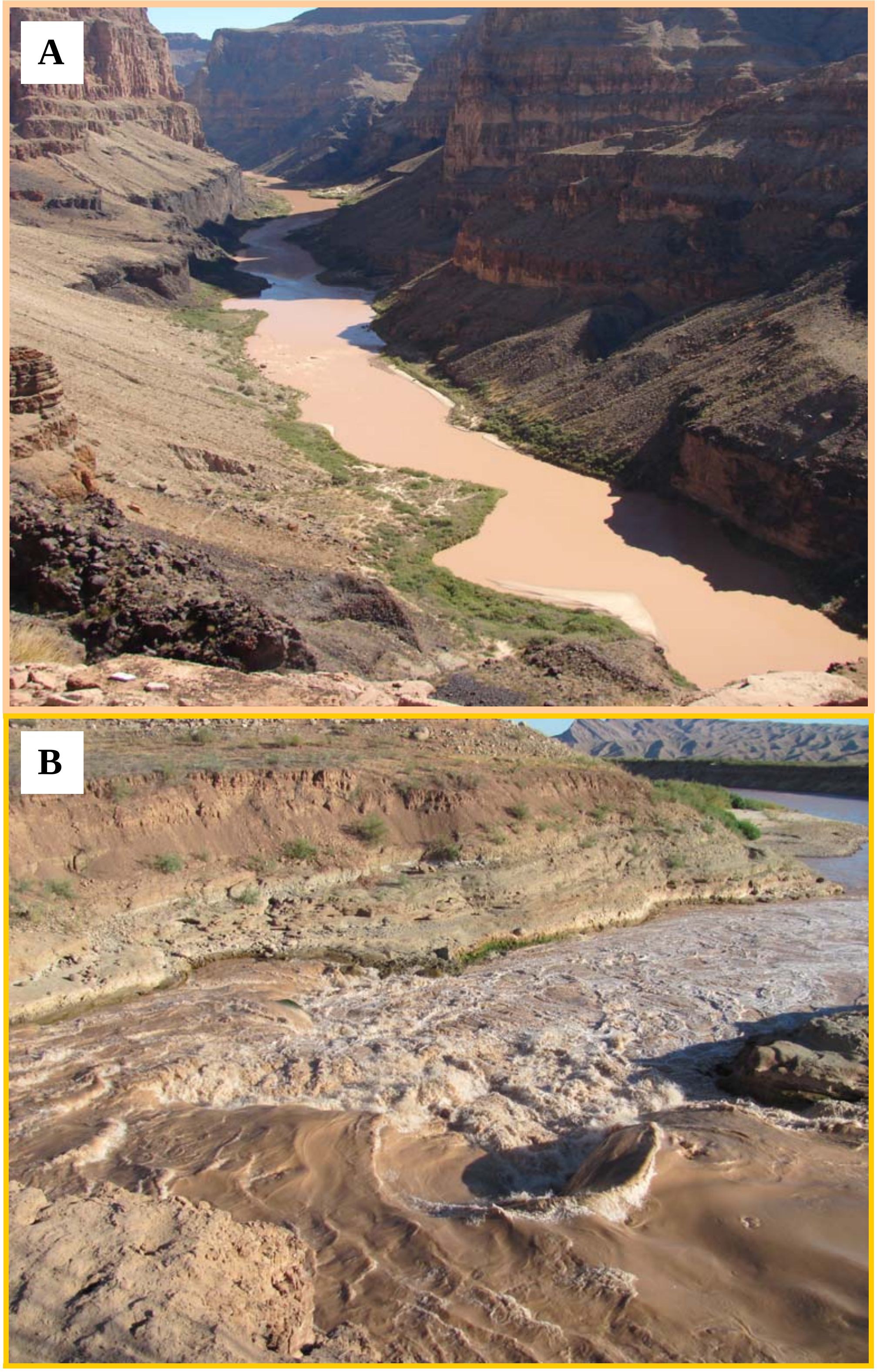

Figure 40. Photos of (A) Colorado River near Whitmore Wash, and (B) large rapid about 1 mi downstream from Pearce Ferry in the Colorado River inflow. Flow of the Colorado River was 9,200–9,300 cfs. Photos taken September 19, 2010, courtesy of (A) J. Stolberg and (B) C. McAda.

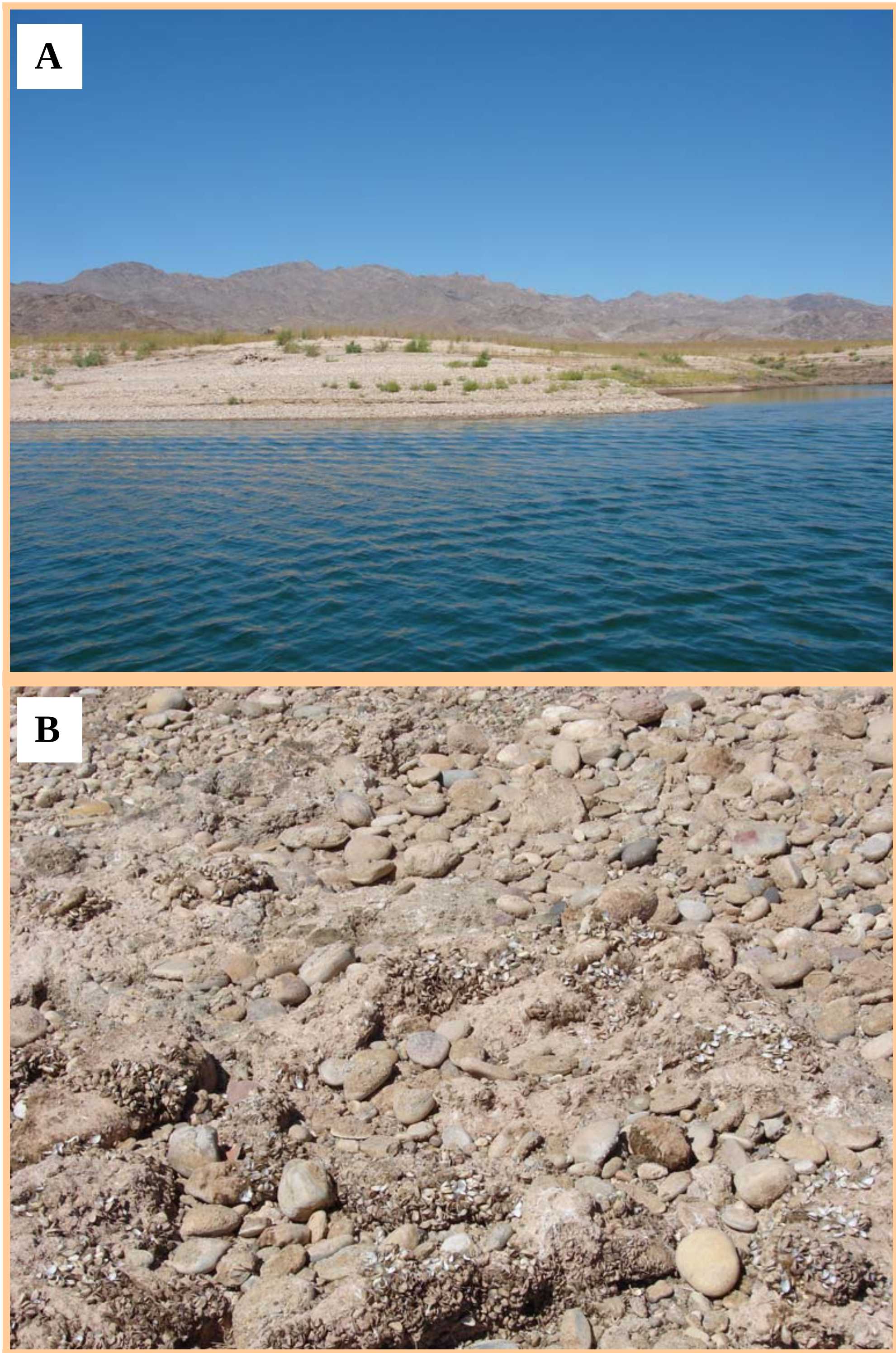

Figure 41. Photos of the Colorado River inflow between Devil's Cove and North Bay showing (A) cobble/gravel islands used by razorback suckers, and (B) clusters of quagga mussels on rock substrate. Lake Mead at low elevation. Photos taken September 19, 2010 by C. McAda.

6.3 Biological Components of Lower Grand Canyon

6.3.1 Food Base

The food base of the Colorado River in the lower Grand Canyon has not been described. Recent samples from Diamond Creek may reflect the macroinvertebrate biomass and species composition for stable substrates, but a large portion of the river channel in the lower Grand Canyon continues to erode and create unstable conditions for invertebrate communities. The river at the interface of Lake Mead has carved a channel into the deltaic sediment deposits where there is a great deal of woody debris that is being washed into the river with the eroding sand banks. This woody debris is rich in organic matter and may be supporting a large, but rather dynamic biomass of invertebrates in what more closely resembles the historical allochthonous productivity system than the autochthonous system found closer to Glen Canyon Dam.

Samples taken in March 2008 from cobble, deposits, and talus habitats at three sites: (A) Lees Ferry (RM 0), (B) the confluence of the Little Colorado River (RM 62), and (C) Diamond Creek (RM 225) show that six taxonomic groups were common but varied by reach and habitat type (Figure 42; Rosi-Marshall et al. 2010). For the downstream-most site at Diamond Creek, the invertebrates were found primarily in cobble and talus. Invertebrates were nearly absent from silt/sand deposits, which is likely reflective of the invertebrate communities in the lower Grand Canyon. These findings highlight the importance of relatively stable features, such as cobble and talus as areas of local productivity, but also suggest that there is little local productivity in the inflow region where channel erosion continues.

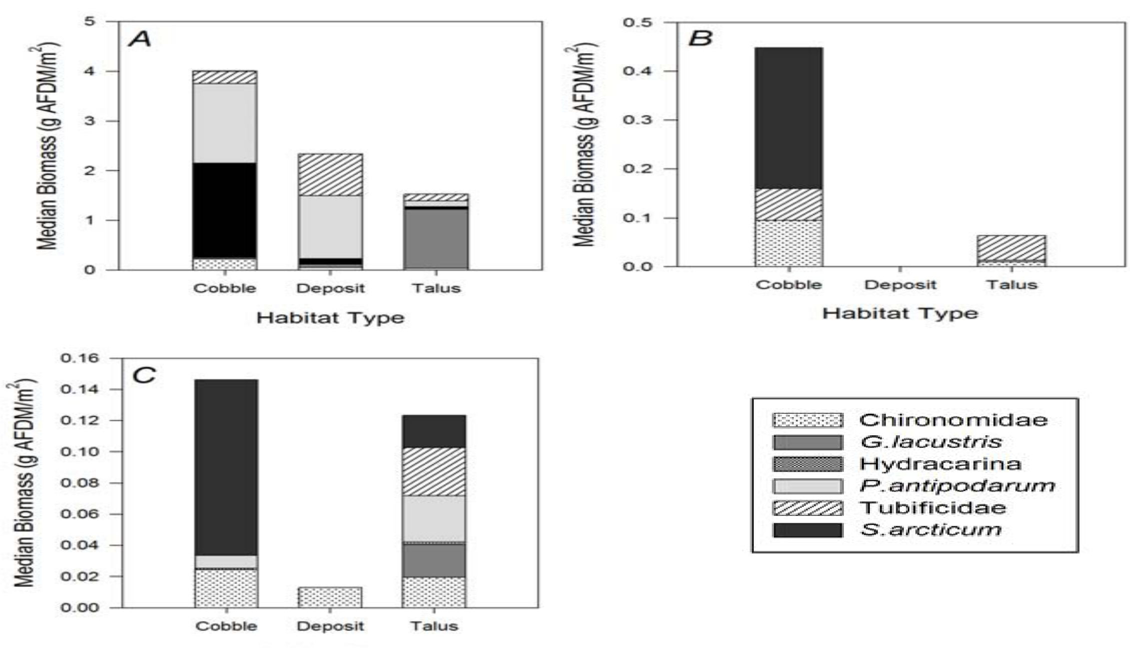

Figure 42. Macroinvertebrate biomass as g AFDM/m² (ash-free dry mass) and relative taxa composition in the three dominant habitat types (cobble, deposits, and talus) at three locations on the Colorado River in Grand Canyon: (A) Lees Ferry (RM 0), (B) Little Colorado River (RM 62), and (C) Diamond Creek (RM 225) in March 2008. Figure from Rosi-Marshall et al. (2010).

6.3.2 Fish Community

There are reportedly 21 species of fish that occur in the Colorado River between Glen Canyon Dam and Pearce Ferry, including 16 introduced and 5 native species; native species include the humpback chub (*Gila cypha*), flannelmouth sucker, bluehead sucker, and speckled dace (*Rhinichthys osculus*) (Valdez and Carothers 1998). The razorback sucker appears to be extirpated from Grand Canyon, but is found as a small reproducing population downstream from the canyon in and below the Colorado River inflow in Lake Mead (Albrecht et al. 2008, 2010).

The largest population of humpback chub in the Colorado River System is found in the Grand Canyon upstream of Diamond Creek, but only one individual has been caught in the lower Grand Canyon during recent surveys; an adult female (329 mm TL) was caught and released at RM 253.2, near Maxon Canyon in October 1993 (Valdez 1994). Evidently, all three species of *Gila* were present in the lower Grand Canyon prior to the inundation by Lake Mead and the subsequent build-up of deltaic deposits. In the 1940's, five humpback chub (*G. cypha*) were collected from the area of Spencer Canyon (near Lava Cliff rapid, RM 246), along with 16 bonytail (*G. elegans*), and six roundtail chub (*G. robusta*) (Miller 1944; Bookstein et al. 1985). Razorback suckers were not reported from these early collections from the lower Grand Canyon.

Contemporary surveys of the fish community between Diamond Creek and Pearce Ferry were conducted during 1992–1995 (Valdez et al. 1995), 2004–2006 (Ackerman et al. 2006), and 2005 (Rogers et al. 2007). The earliest survey took place when Lake Mead was at a high level, and the other two took place at a low reservoir level (Figure 43). Because the lower Grand Canyon is part of the inflow region of Lake Mead, there were substantial differences in habitat conditions during the two surveys. For the first survey, the river between Separation Canyon (RM 240) and Emery Falls was wide and slow-flowing with a flat-bed channel of sand and silt that was lined with dense stands of riparian vegetation. Downstream of Emery Falls, there was an expansive area of water, as a lake-type habitat, that inundated much of the riparian vegetation and Pearce Ferry Bay (Figure 44).

A standard fish monitoring program has been in effect for several years from Glen Canyon Dam to Diamond Creek (e.g., Makinster et al. 2007, 2008, 2009), but has not been extended downstream on a regular basis. During June 2007 and July 2008, the AGFD, in cooperation with GCMRC, launched a pilot project to investigate movement of channel catfish (*Ictalurus punctatus*) from the Lake Mead inflow into the Grand Canyon, since channel catfish are considered a principal predator of the humpback chub. A number of gears were deployed and evaluated, including angling, electrofishing, and baited hoop nets. Catches of channel catfish were variable and the number of individuals does not appear to be stable in the lower Grand Canyon—possibly as a consequence of the dynamic nature of the inflow.

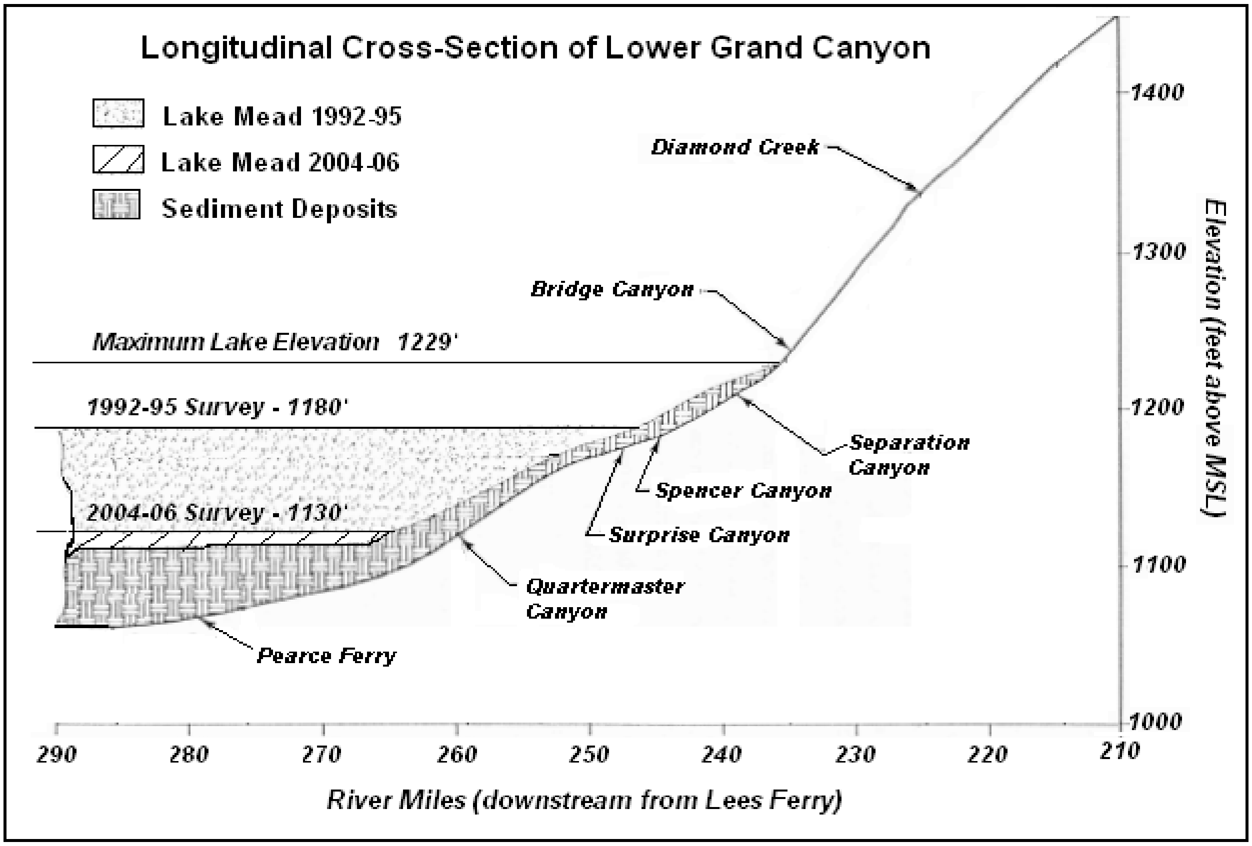

Figure 43. Longitudinal cross-section of the lower Grand Canyon from Diamond Creek to Pearce Ferry, showing the elevational gradient of the Colorado River, the deltaic sediment deposits, and the approximate elevations of Lake Mead during the 1992–95 and 2004–06 fish surveys.

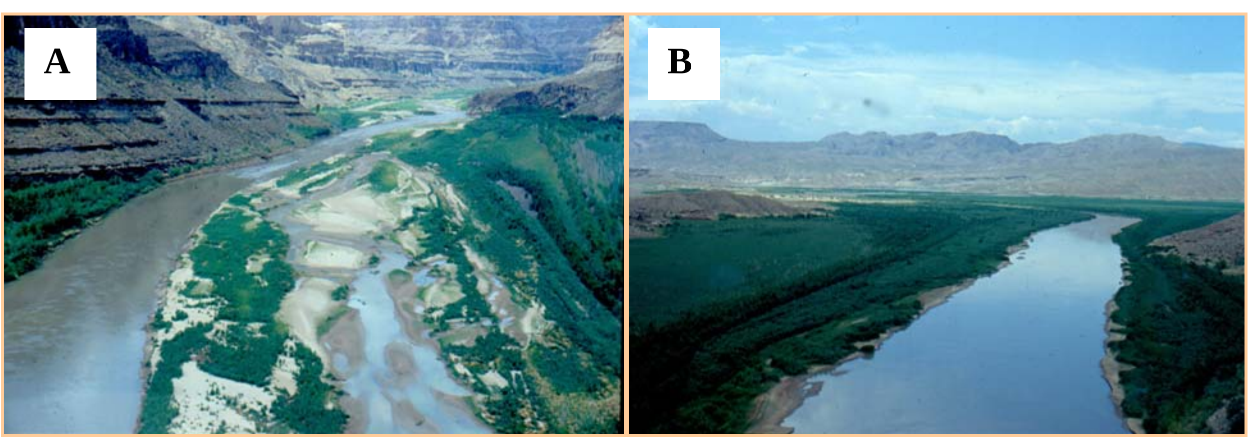

Figure 44. Aerial views of the lower Grand Canyon taken in June 1992 showing (A) the deltaic sediments deposits and growths of riparian vegetation near Emery Fals, and (B) the widened river channel at the interface of the Colorado River and Lake Mead in the Pearce Ferry Bay. Photos by R. Valdez.

During 1992–1995, seven species made up about 95% of the total fish composition; red shiners (*Cyprinella lutrensis*) were the most abundant, followed by common carp (*Cyprinus carpio*), threadfin shad (*Dorosoma petenense*), and fathead minnow (*Pimephales promelas*). Channel catfish, mosquitofish (*Gambusia affinis*), and flannelmouth suckers were less common (Table 19). The 2004–2006 survey was conducted at a much lower reservoir level when the river was carving a channel through the deltaic deposits. The fish community was still dominated by nonnative species such as red shiners, common carp, channel catfish, and mosquitofish, but native species including the speckled dace and flannelmouth sucker were far more abundant than during 1992–1995 (Figure 45).

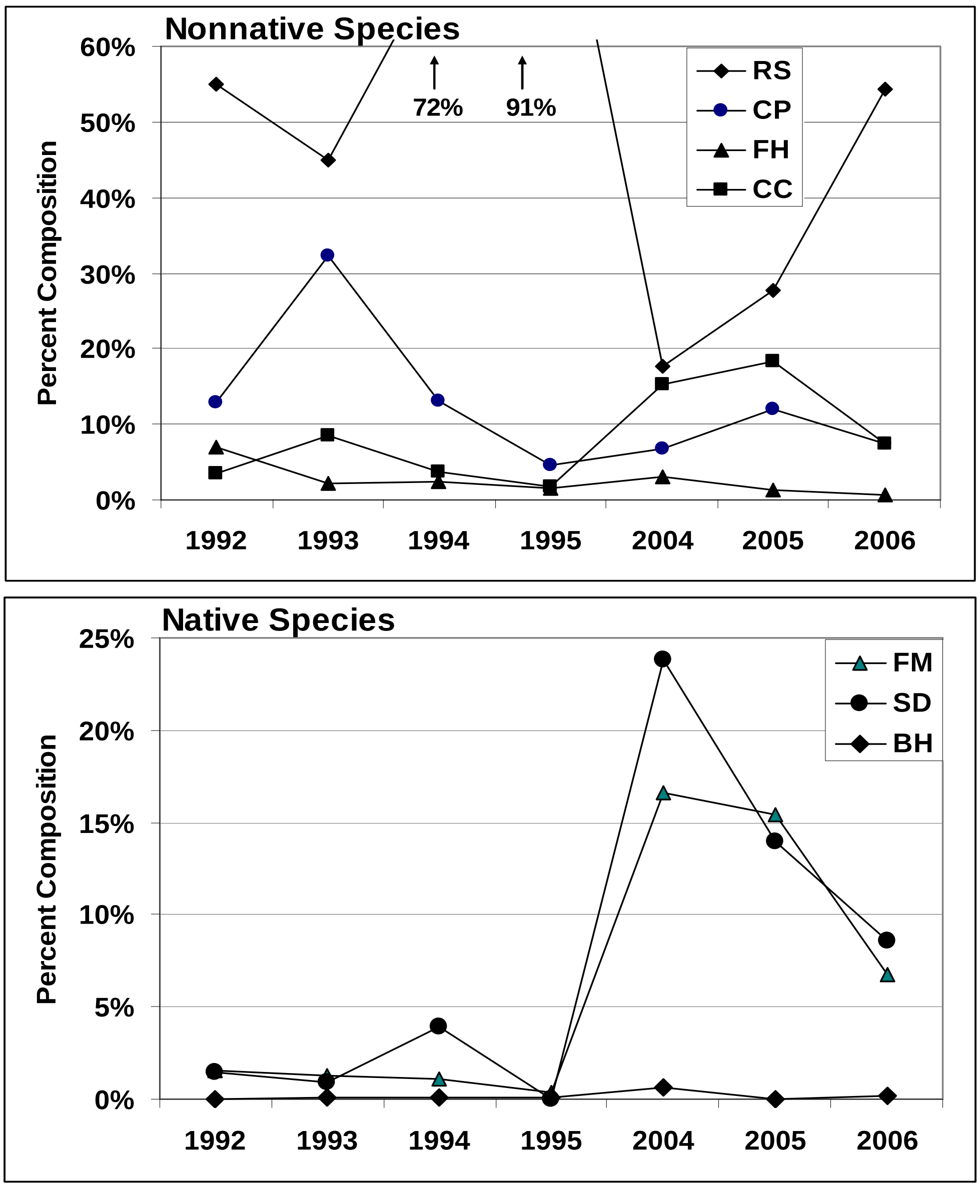

Figure 45. Percent of total number of fish caught by year from Diamond Creek to Pearce Ferry. Data for 1992–1995 from Valdez et al. (1995) and for 2004–2006 from Ackerman et al. (2006). See Table 19 for species codes.

For the period 1992–1995, the longitudinal distribution of fish species from Whitmore Wash (RM 189) to below Pearce Ferry (RM 286) was dramatic, largely because the deltaic sediment deposits filled the river channel and reduced habitat complexity below about Bridge Canyon (RM 235). The interface of the Colorado River with the Lake Mead inflow created a slow-flowing environment more conducive to introduced nonnative fishes (Figure 46). The reach from Whitmore Wash to Diamond Creek was dominated by three native species, the speckled dace, flannelmouth sucker, and bluehead sucker, with smaller proportions of nonnative carp, fathead minnows, and channel catfish. The reach from Diamond Creek to Bridge Canyon was dominated by carp and channel catfish, although speckled dace, flannelmouth suckers, and bluehead suckers persisted.

The longitudinal transition in the fish community was most dramatic below Bridge Canyon, where sediment deposits had transformed the historical river channel into a flat uniform channel. Dominant species were red shiners, carp, fathead minnows, and channel catfish. Downstream of Emery Falls, the fish community was more indicative of a lake-like environment, and was dominated by threadfin shad, carp, and red shiners. This longitudinal transition in the fish community was changed to a more uniform pattern of species as the reservoir dropped and the river eroded a new channel into the sediment deposits. Some of the historical habitat, such as rock outcrops and bottom rock substrates are becoming exposed and the fish community in the lower Grand Canyon is transitioning toward a native fish community, dominated by speckled dace, flannelmouth suckers, and bluehead suckers.

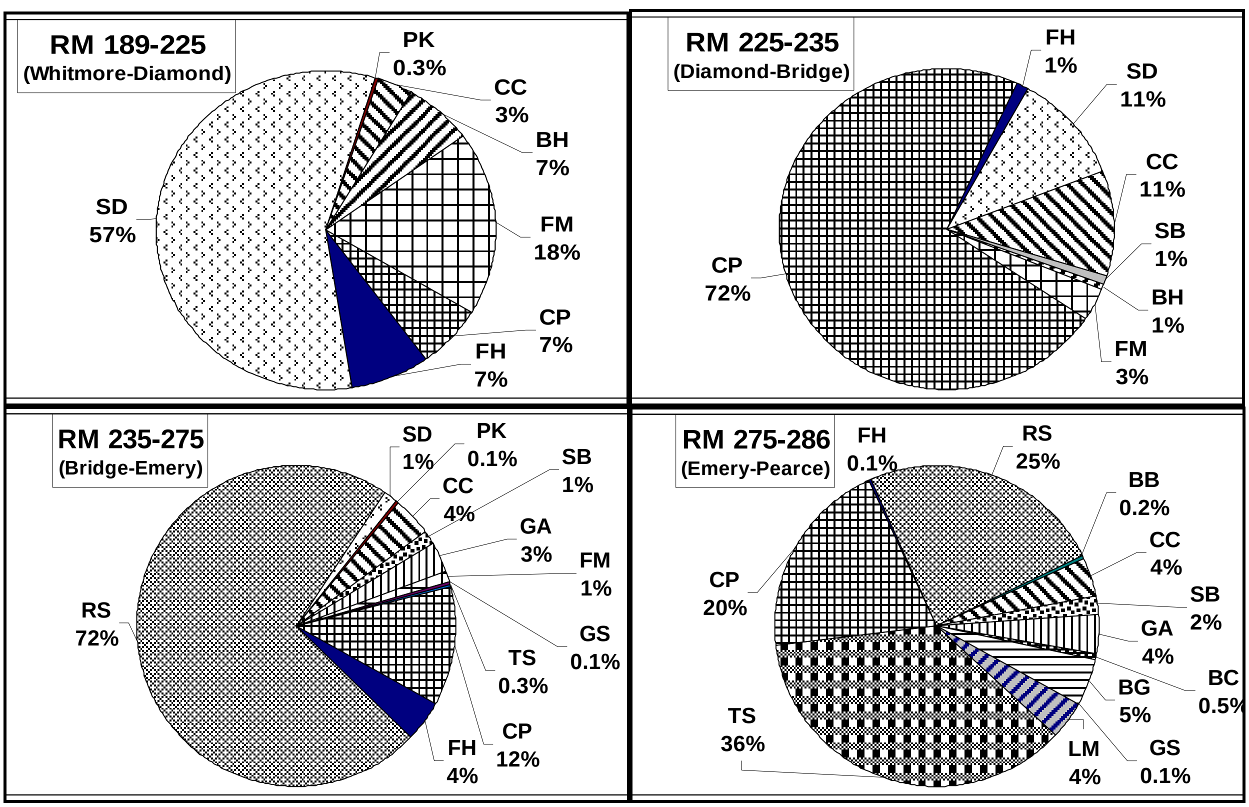

Figure 46. Percentage of fish composition for Whitmore Wash to Diamond Creek (RM 189–225), Diamond Creek to Bridge Canyon (RM 225–235), Bridge Canyon to Emery Falls (RM 235–275), and Emery Falls to below Pearce Ferry (RM 275–286) during 1992–1995. See Table 19 for data and species codes.

Table 19. Number and percent of fish species caught in the Colorado River from Diamond Creek to Pearce Ferry. Data for 1992–1995 from Valdez et al. (1995) and for 2004–2006 from Ackerman et al. (2006).

Species Name and Code	1992		1993		1994		1995		2004		2005		2006		Total
	No.	Per.	No.	Per.	No.	Per.	No.	Per.	No.	Per.	No.	Per.	No.	Per.	
Red shiner - RS	1351	54.9%	913	45.0%	1792	71.8%	937	91.2%	87	17.6%	191	27.8%	1247	54.3%	6518
Common carp - CP	315	12.8%	656	32.4%	327	13.1%	48	4.7%	33	6.7%	82	11.9%	168	7.3%	1629
Threadfin shad	310	12.6%	10	0.5%	0	0.0%	0	0.0%	0	0.0%	1	0.1%	0	0.0%	321
Fathead minnow - FH	174	7.1%	44	2.2%	58	2.3%	16	1.6%	15	3.0%	9	1.3%	13	0.6%	329
Channel catfish - CC	85	3.5%	171	8.4%	90	3.6%	19	1.9%	76	15.4%	126	18.3%	169	7.4%	736
Mosquitofish	68	2.8%	109	5.4%	52	2.1%	2	0.2%	80	16.2%	8	1.2%	221	9.6%	540
Flannelmouth sucker - FM	38	1.5%	25	1.2%	28	1.1%	4	0.4%	82	16.6%	106	15.4%	154	6.7%	437
Bluegill	37	1.5%	1	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	1	0.0%	39
Speckled dace - SD	36	1.5%	18	0.9%	98	3.9%	0	0.0%	118	23.8%	96	14.0%	196	8.5%	562
Largemouth bass	23	0.9%	12	0.6%	9	0.4%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	44
Striped bass	14	0.6%	51	2.5%	38	1.5%	0	0.0%	0	0.0%	60	8.7%	114	5.0%	277
Black crappie	2	0.1%	2	0.1%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	4
Black bullhead	2	0.1%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	2
Walleye	2	0.1%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	2
Plains killifish	1	0.0%	4	0.2%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	5	0.2%	10
Green sunfish	1	0.0%	6	0.3%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	1	0.0%	8
Bluehead sucker - BH	0	0.0%	1	0.0%	2	0.1%	1	0.1%	3	0.6%	0	0.0%	5	0.2%	12
Smallmouth bass	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	4	0.6%	2	0.1%	6
Humpback chub	0	0.0%	1	0.0%	0	0.0%	0	0.0%	0	0.0%	4	0.6%	0	0.0%	5
Rainbow trout	0	0.0%	3	0.1%	1	0.0%	0	0.0%	1	0.2%	0	0.0%	0	0.0%	5
Golden shiner	0	0.0%	0	0.0%	1	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	1
Total	2459	100%	2027	100%	2496	100%	1027	100%	495	100%	687	100%	2296	100%	11487

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APPENDIX A: RAZORBACK SUCKER HABITAT SUITABILITY INDICES FROM SCIENTIFIC REPORTS

Habitat Suitability Indices – Upper Colorado River Basin

(From Valdez et al. 1987)

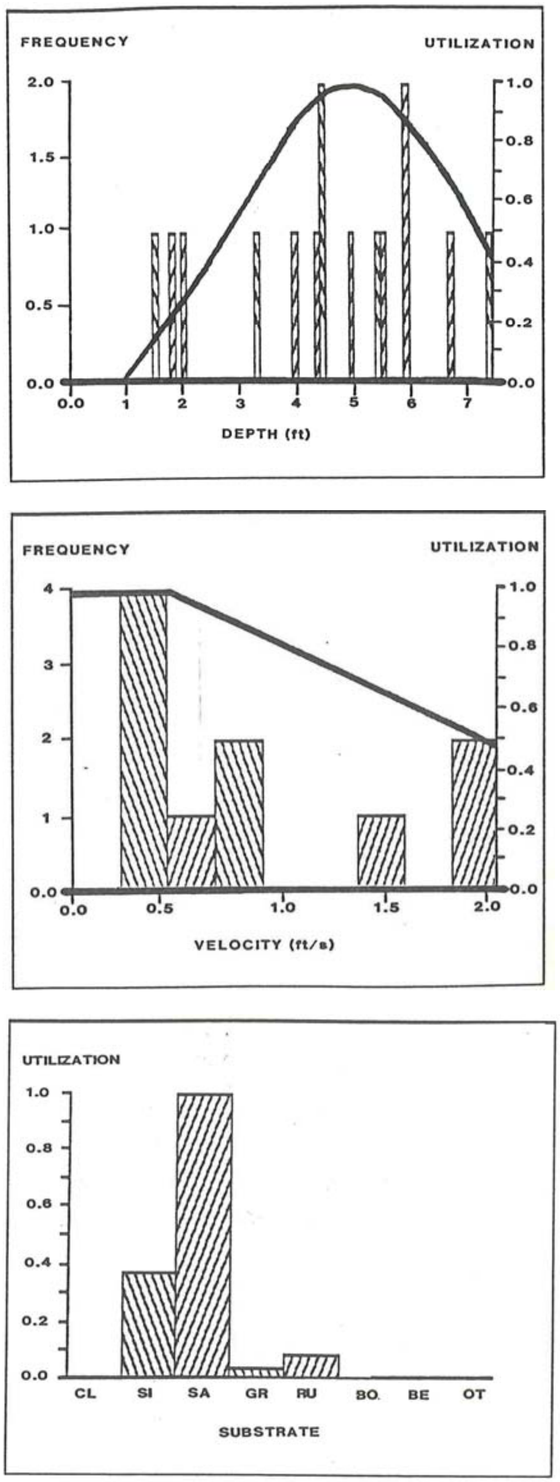

Figure A-1. Habitat suitability index (HSI) criteria (depth, velocity, substrate) for adult razorback suckers observed in the Green River May–June.

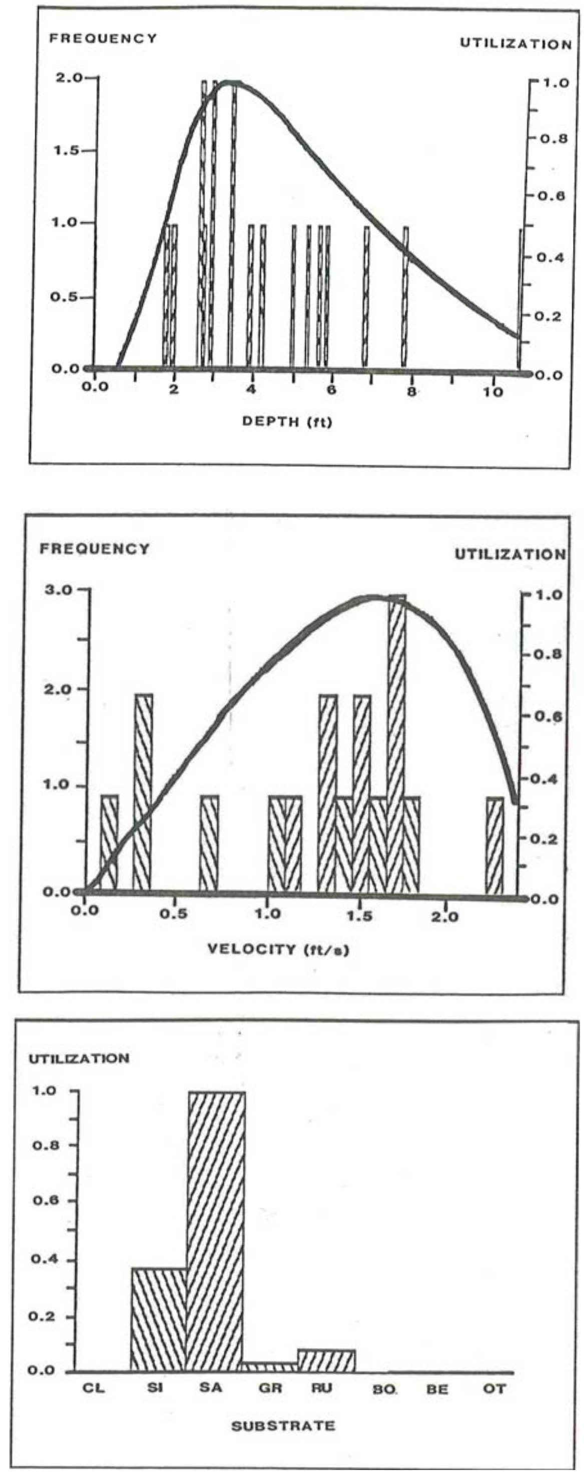

Figure A-2. Habitat suitability index (HSI) criteria (depth, velocity, substrate) for adult razorback suckers observed in the Green River July–October.

Habitat Suitability Indices – Upper Colorado River, 15-Mile Reach

(Data collected in Grand Valley, Colorado, during 1986, 1987, and 1988. N = number of observations; n = number of different suckers. From Osmundson and Kaeding 1989)

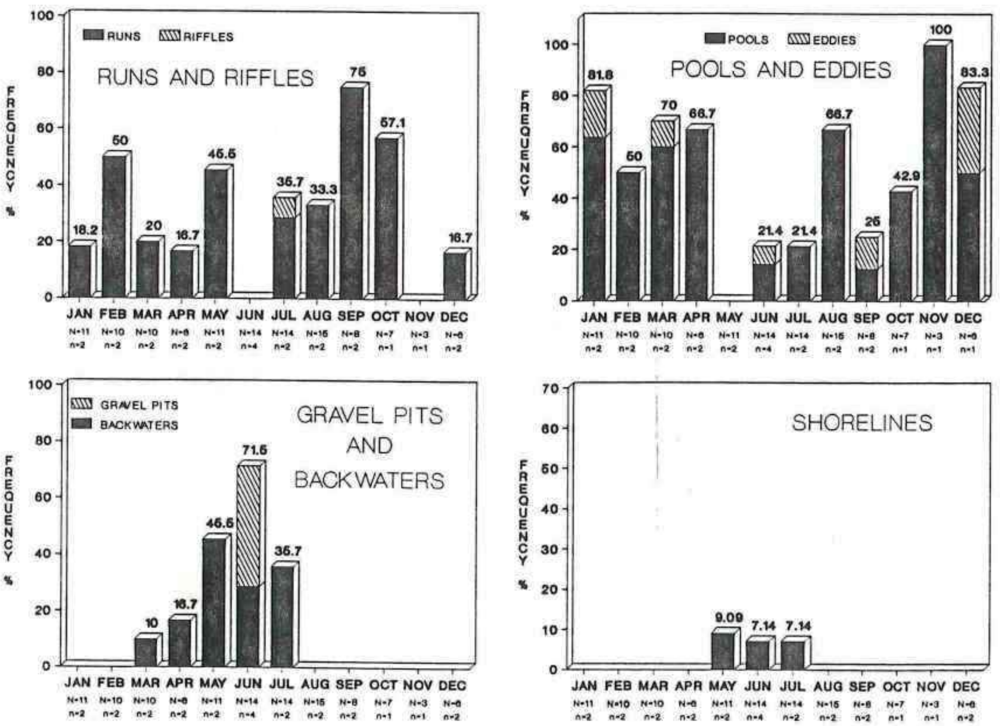

Figure A-3. Mesohabitat used by four radio-tagged razorback suckers by month.

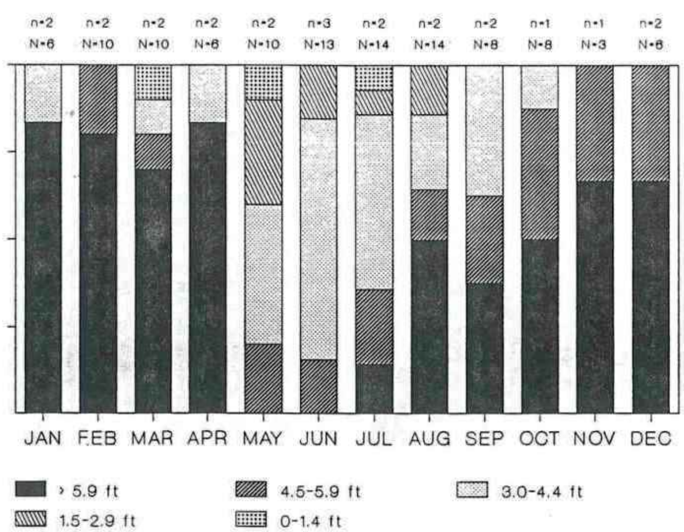

Figure A-4. Frequency of depths at locations of radio-tagged razorback suckers by month.

Habitat Suitability Indices – Upper Colorado River, 15-Mile Reach

(Osmundson and Kaeding 1989)

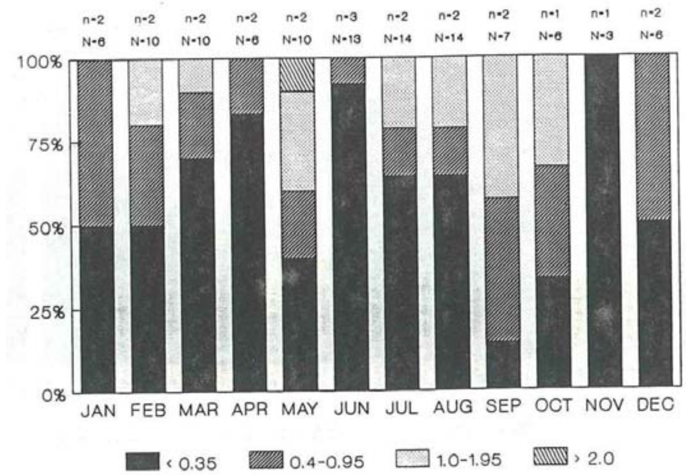

Figure A-5. Mean depth at location of four radio-tagged razorback suckers by month.

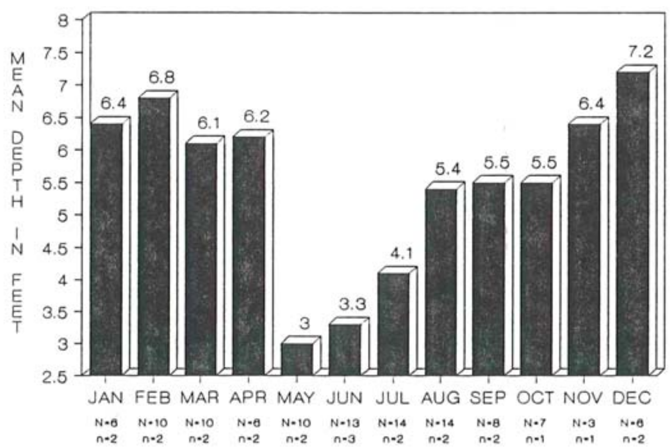

Figure A-6. Frequency of mean column velocity (in cubic feet per second) at locations of four radio-tagged razorback suckers by month.

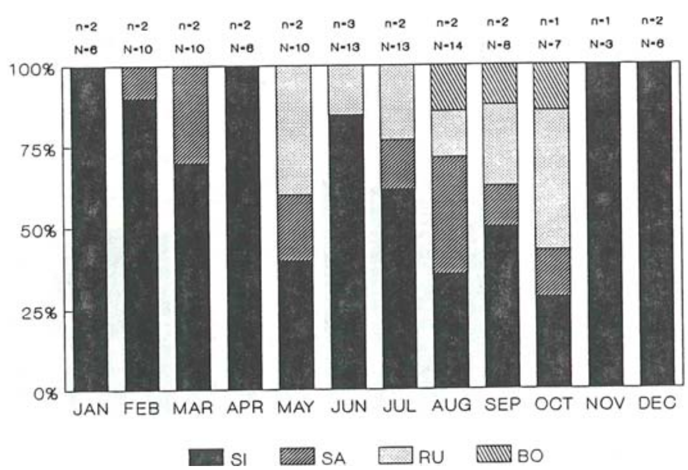

Figure A-7. Frequency of substrate type at locations of four radio-tagged razorback suckers by month.

Habitat Suitability Indices – Upper Colorado River
(Valdez et al. 1982)

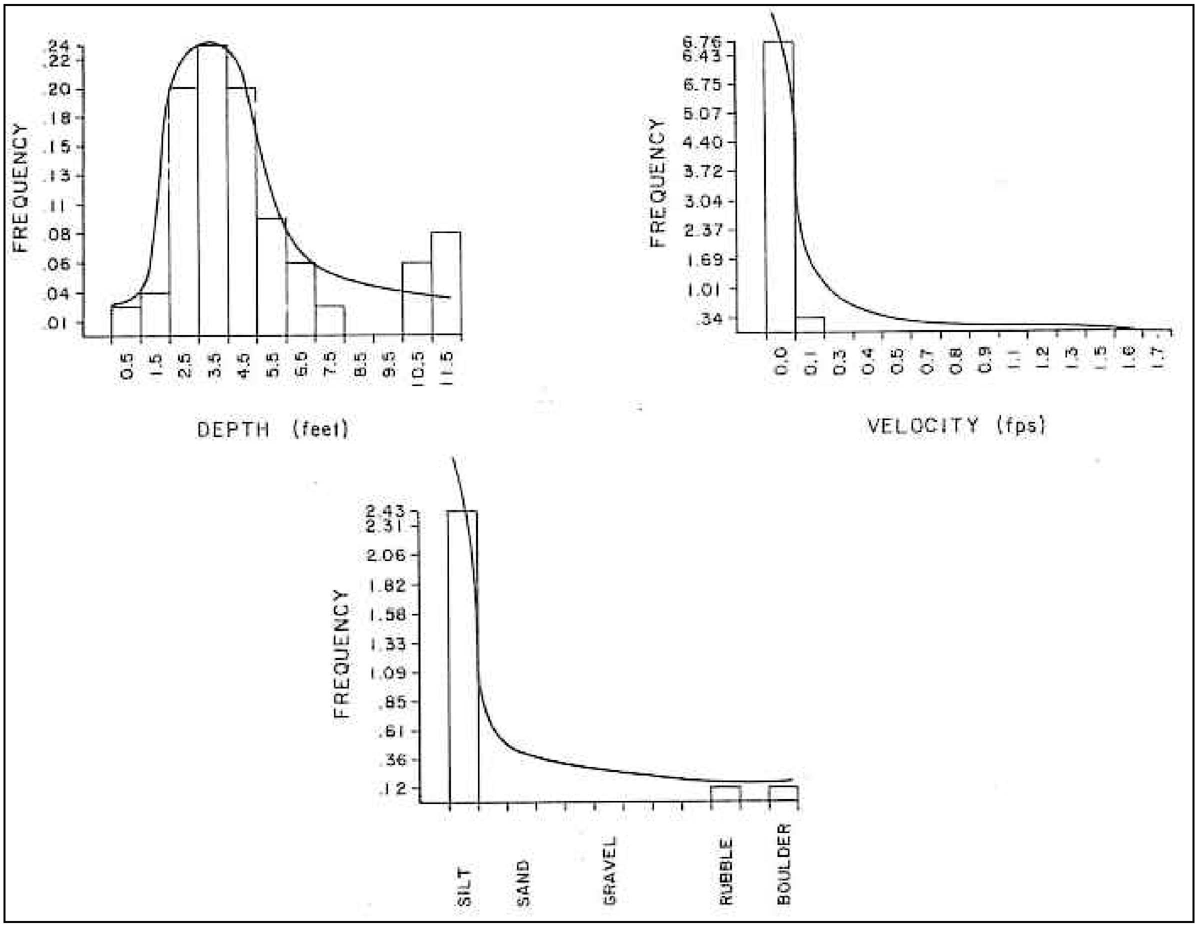

Figure A-8. Habitat suitability index (HSI) criteria (depth, velocity, substrate) for adult razorback suckers captured in the upper Colorado River, 1979–1981.

Habitat Suitability Indices – Green River (winter)
(Valdez and Masslich 1989)

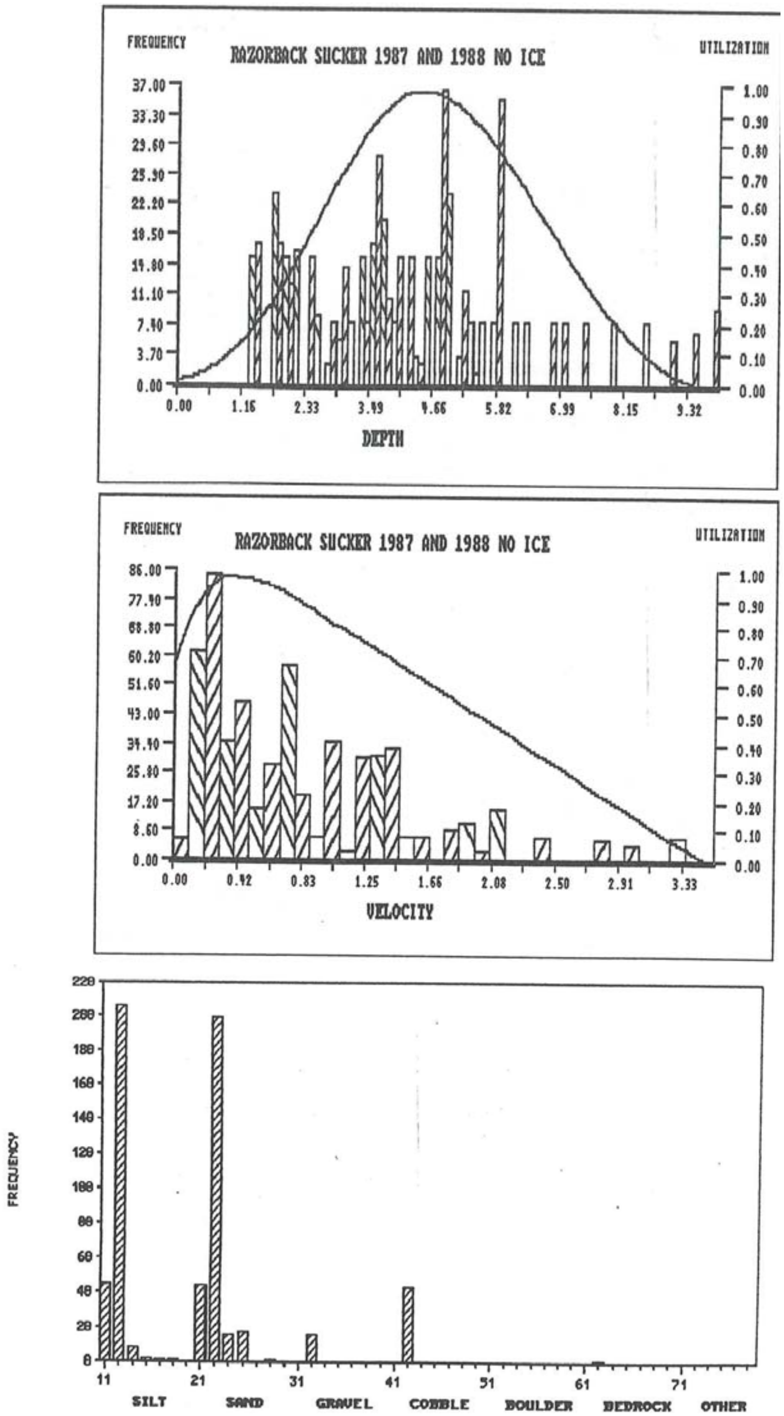

Figure A-9. Habitat suitability index (HSI) criteria (depth, velocity, substrate) for razorback sucker overwinter use from 1987 and 1988 no ice data.

Habitat Suitability Indices –Verde River

(Clarkson et al. 1993)

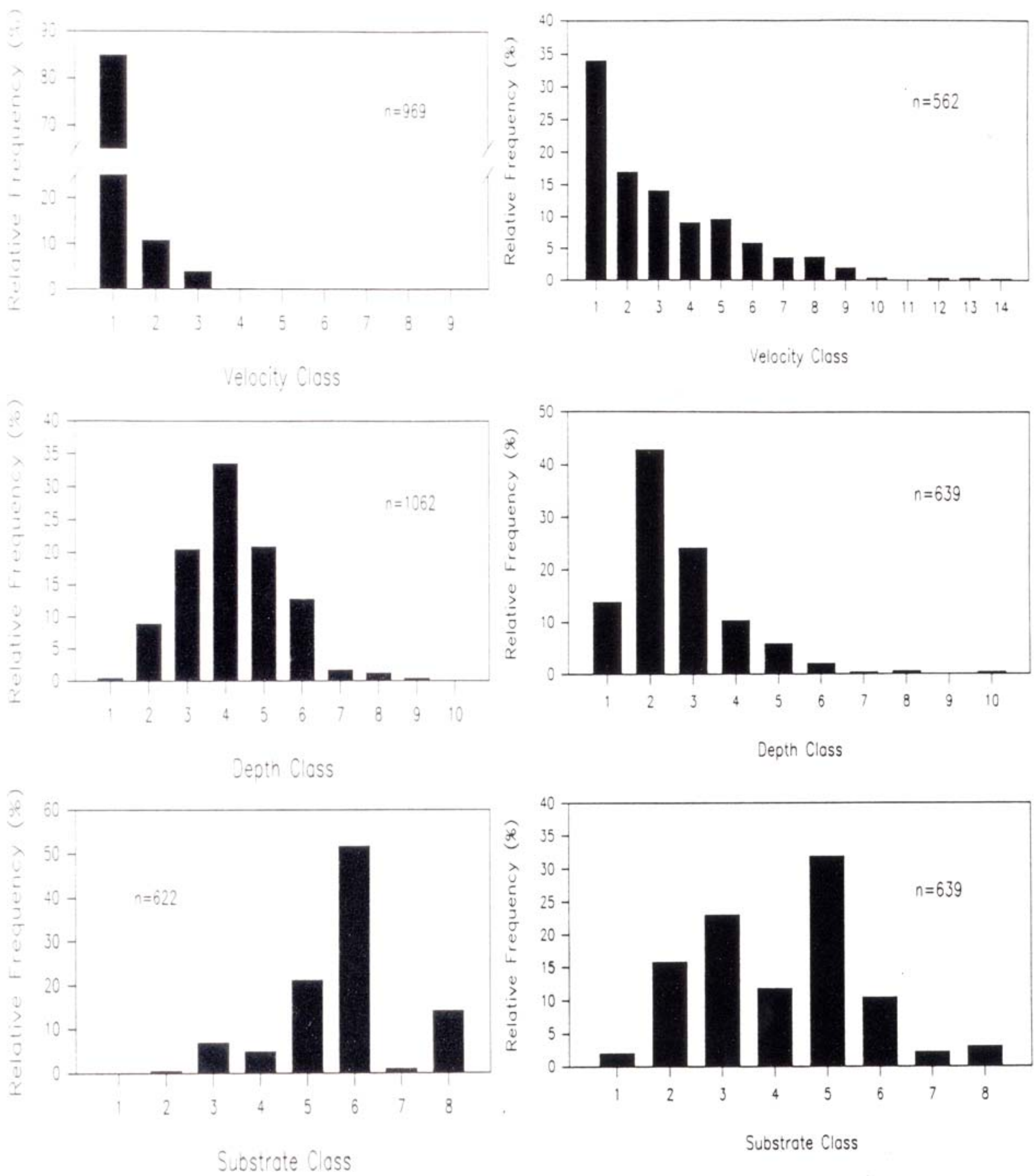

Figure A-10. Frequency distributions for velocity, depth, and substrate (A) available in the Verde River, and (B) used by 24 radio-tagged subadult and adult razorback suckers in the Verde River, 1991–92.

APPENDIX B: PRELIMINARY SURVEY OF LOWER GRAND CANYON (SPEAS AND TRAMMELL 2009)

Table B-1. Aquatic habitat characteristics by river mile in lower Grand Canyon; preliminary results of 2009 field survey (Speas and Trammell 2009). Color-coded columns to the left highlight the presence or absence of cobble substrate, gravel substrate, and backwaters. Gray rows mark major channel type break points. *We wish to thank Dave Speas and Melissa Trammell for providing the information regarding their 2009 survey presented in this report. The results shown here are preliminary and should be understood as such. Results from this field survey should not be cited or copied without permission of the authors.*

Cobble Substrate	Gravel Substrate	Backwater	RM[1]	Backwaters	BW right	BW left	BW wpt	Temp °C	Hab 1[2,3]	Hab 2[2,3]	Hab 3[2,3]	# Hab[4]	Cover[5]	Islands	Complex ?[6]	Comments
			181	1	na	1	269		RU	ED	BW	3	VG	1	Y	BW with vegetation (cattails)
			185	1	na	1	na		ED	RI	RU	3	na	0	N	1 small BW likely better at low water
			187	1	1	na	271		RU	ED		2	VG	0	N	187 mi rapid; lots of shoreline phrag. Small BW, big eddy
			188	0	na	na	na		RI	RU	ED	3	na	1	Y	Cobble island with shoals; Whitmore wash with gravel
			189	0	na	na	na		ED	RU		2	na	0	Y	Submerged cobble island w/submerged BW hab; RM 190 w granite islands
			191	2	1	1	272		RI	RU		2	na	1	Y	Submerged cobble island at 191; BWs at 191.2, 191.3, 191.5; Good BW at 191 during 9/08 is now gone
			192	1	1	na	274		RI	ED		2	VG	1	Y	BW at 192
			193	1	na	1	275	16	RU	ED	RI	3	VG	3	Y	Temp taken at 1028 am; 2 cobble islands w shoals, big eddies, lots of shoreline veg (phrag); BW at RM 194 L marshy, Phragmites, waypt 275, not sampled last Sept, full of sucker larvae (15-25 mm) and age 1 FMS (80 mm).

Cobble Substrate	Gravel Substrate	Backwater	RM[1]	Backwaters	BW right	BW left	BW wpt	Temp ºC	Hab 1[2,3]	Hab 2[2,3]	Hab 3[2,3]	# Hab[4]	Cover[5]	Islands	Complex ?[6]	Comments
			194	0	na	na	na		RI	RU		2	VG	1	Y	1 almost BW (flow thru), lg debris fan at 194 mi cyn., gravel deposits, shoreline veg (phrag); Below Lava: suitable in many ways, why not here?
			196	1	1	na	276		RU	RI		2	na	1	Y	Complex at top; nice BW at frogy fault, big debris fan, island at 197 with shoal
			198	1	1	na	277		RI			1	na	1	Y	Parashant riffle, debris fan, long cobble island, BW on river right at RM 199
			199	1	na	1	278		RI	RU		2	VG	1	Y	Lg island at RM 199.5; 1 BW at RM 200; no GPS signal? Wpt 278 maybe; shoreline veg (phrag)
			200	0	na	na	na	16	RI	RU		2	na	2	Y	Temp taken at 1140; submerged almost BW at RM 200.3 L, sm island at 200.6 L, Cobble islnad at 201 R.
			201	1	na	1	279		ED	RI		2	na	0	Y	Big eddy at 201.1 L should have a BW but doesn't; sm eddy just below has BW; cobble shoals, riffle at 202
			202	2	2	na	280	16.5	ED	RI		2	na	1	Y	Temp at 1330 after lunch; cobble island, nice BWs, big eddies
			204	2	2	na	281, 282		ED	RI		2	na	1	Y	Cobble BW at top of riffle, RM 204.3; Two big eddies at RM 204.8, 2 BW flow thrus at river right
			205	0	na	na	na		RI	ED	RA	3	na	2	Y	Cobble with shoals
			208	1	na	1	na		RU	ED	RI	3	na	1	Y	Riffle before 209 rapid; big island at 209

Cobble Substrate	Gravel Substrate	Backwater	RM[1]	Backwaters	BW right	BW left	BW wpt	Temp ºC	Hab 1[2,3]	Hab 2[2,3]	Hab 3[2,3]	# Hab[4]	Cover[5]	Islands	Complex ?[6]	Comments
			210	0	na	na	na		RU	ED		2	na	0	N	Moderate runs, eddies; talus slopes; less veg. than above 209; backwaters on left missing since last sept; one small cobble bar
			214	0	na	na	na		ED	RU		2	na	0	N	One cobble bar; deep slow eddies and runs, much bedrock
			216	0	na	na	na		RU	ED		2	VG	0	N	Flow thru on left; talus/vg shore; slow runs; much gravel from side canyons
			217	0	na	na	na		RU	ED	RA	3	VG	0	N	Above 217 rapid: slow runs w/ talus, bedrock, vg; thick vegetation returning; below 217: bedrock, rapids, deep channel, slow surges, one cobble on left. Slow runs = "pools"
			220	1	na	1	284	17	RI	ED		2	VG	1	Y	Flooded veg, small cobble/long riffles, BW still at 220.3 L but degraded (photo); beach face eroded, BW maybe backfilled. BW temp 22, MC 17 C; full of sucker larvae, FMS to age 1, dace of various sizes. Will be isolated pool at low water.
			221	0	na	na	na		RU	RI		2	VG	0	Y	Veg, debris fan, bedrock; slow runs and cobble riffles (3); diverse shoreline types
			222	0	na	na	na		RU	RI	RA	3	na	1	Y	Island, diverse shoreline types, bedrock, talus, DF, VG; moderate runs, cobble riffles (side channel of island), 1 rapid

Cobble Substrate	Gravel Substrate	Backwater	RM[1]	Backwaters	BW right	BW left	BW wpt	Temp °C	Hab 1[2,3]	Hab 2[2,3]	Hab 3[2,3]	# Hab[4]	Cover[5]	Islands	Complex ?[6]	Comments
			223	0	na	na	na		RI	RA		2	na	1	Y	Diverse shoreline types/hab, cobble riffles (2), missing backwater on left, bedrock cobble/talus, veg, etc…flow thru on rit side, 1 rapid, turns into bedrock, slow.
			225	0	na	na	na		RU			1	VG	0	N	More veg than immediately above, bedrock, some debris fan/talus. Slow runs. 1 cobble point on rt.
			229	2	2	na	285,286					0	na	0	Y	Sm. BW at top of travertine rapid GPS 285, BW 229.3 R gps spt 286.
			236	1	na	1	287		ED	RA		2	na	0	N	Sm BW RM 237, gps 287
			238	1	1	na	288		ED			1	na	0	N	More deep swirlies; fluted rocks, 8.6 mph boat speed; BW at 238.8 gps wpt 288 (downstream of BW about 1/4 mi)
			239	1	na	na	289		ED			1	na	0	N	Sm BW at 239.4, gps 289; almost BW also
			240	3	na	3	na	17	RU			1	na	0	N	Mostly slow deep runs; occasionally sandbar deposits with small BWs; T taken at 920
			241	1	1	na	290		RU			1	na	0	N	BW at 241.1, gps 290
			242	2	2	na	na		RU			1	na	0	N	Long slow run from here on down; sm BW at 242.5, gps 291; Nice BW at 242.7 R, gps 292
			243	1	1	na	293	17.5	RU			1	na	0	N	"Mile 243 camp"; nice BW with many larval and age 1 suckers; no NNF seen! Temp in BW 18.5 C; MC = 17.5 C at 947
			244	2	1	1	294,295		RU			1	na	0	N	BW at 244.2 gps 294; Nice BW at 244.3 gps 295

Cobble Substrate	Gravel Substrate	Backwater	RM[1]	Backwaters	BW right	BW left	BW wpt	Temp ºC	Hab 1[2,3]	Hab 2[2,3]	Hab 3[2,3]	# Hab[4]	Cover[5]	Islands	Complex ?[6]	Comments
			246	1	1	na	297		RU			1	na	0	N	BW at 246.3 R, gps 297
			247	1	na	na	298		RU			1	na	0	N	BW river right 247; gps 298 (sat coverage poor)
			249	1	1	na	na		RU	RI		2	na	0	Y	RM 248.8 Surprise Canyon, nice cobble bar, BW below; beginning to downcut thru lake sediments at about 20' above river
			250	1	na	1	299, 300		RU			1	na	0	N	Nice BW at river left RM 250.5, gps 299; BW at 250.6R, gps 300
			253	1	na	1	na		RU			1	na	0	N	BW at 253.9 L; starting sandbar formation (riverbed)
			255	1	na	1	na		RU			1	TURB	0	N	BW 255.0L
			258	1	na	na	303		RU			1	TURB	0	N	Small BW gps 303
			259	1	1	na	304		RU			1	TURB	0	N	RM 259.3 R gps 304; submerged bars
			263	1	1	na	305	18	RU			1	TURB	0	N	BW 263 R, gps 305, water temp 18 C
			265	1	1	na	na		RU			1	TURB	2	N	Sand bars="islands"; some nearshore cover, not much; more of same--mid channel bars w some veg on them; low water backwater

[1] River miles from Stevens, L. 1983. The Colorado River in Grand Canyon. Red Lake Books, Flagstaff, Arizona.
[2] Hab 1=dominant habitat type; Hab 2=secondary habitat type; Hab 3=tertiary habitat type
[3] RU=run; RI=riffle; ED=eddy; BW=backwater; RA=rapid
[4] # Hab=Number of habitat types present
[5] Cover=overhanging or turbidity; VG=terrestrial vegetation; TURB=sediment turbidity
[6] Complex=Categorical variable based on presence of habitat for multiple life stages (more than one habitat type present; backwaters, riffles, islands, side channels, etc.)