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Species Status Assessment Report
for the
Razorback Sucker *Xyrauchen texanus*



U.S. Fish and Wildlife Service
Mountain-Prairie Region (6)
Denver, Colorado

PREFACE

This Species Status Assessment provides an integrated, scientifically sound assessment of the biological status of the endangered razorback sucker *Xyrauchen texanus*. This document was prepared by the U.S. Fish and Wildlife Service (USFWS) with assistance from state, federal, and private researchers currently working with razorback sucker. The writing team would like to acknowledge the substantial contribution of time and effort by fisheries biologists who participated in the Delphi survey reported in Section 6 of this Species Status Assessment and from those that participated in the Science Team for Scenario Development.

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EXECUTIVE SUMMARY

This Species Status Assessment (SSA) provides an integrated assessment of the status and viability of the razorback sucker (*Xyraunchen texanus*) across eight populations. The SSA first establishes the essential requirements of razorback sucker by describing the species, its resource needs and the risk and conservation factors affecting it. Next, the SSA evaluates the current condition of the species through an assessment of physical habitat conditions and demographic responses under existing environmental and anthropogenic factors. To assess potential future condition, the SSA presents forecasts of razorback sucker response to multiple probable future scenarios under a biologically meaningful timeframe. Considering the uncertainties of each future scenario, the species is evaluated within the context of resiliency, redundancy and representation.

Species Overview

The razorback sucker (family Catostomidae) is a fish endemic to the warm-water portions of the Colorado River basin of the southwestern United States. Razorback sucker are found throughout the basin in both lotic and lentic habitats, but are most common in low-velocity habitats such as backwaters, floodplains, flatwater river reaches and reservoirs. Razorback sucker prefer cobble or rocky substrate for spawning, but have been documented to clear sediment away from cobble when conditions are unacceptable and even spawn successfully over clay beds. Depending on the subbasin, juveniles and adults frequently have access to appropriate habitat throughout the system ranging from backwaters and floodplains to deep and slow-moving pools, however nonnative fishes are frequently found in such habitats as well. The species is tolerant of wide-ranging temperatures, high turbidity and salinity, low dissolved oxygen and wide-ranging flow conditions. Razorback sucker typically become sexually mature between three and four years of age, can live for more than 40 years, and spawn multiple times over a lifespan. Razorback sucker consume a large array of food items depending on the environment in which they live.

The historical range of the species includes most of the Colorado River basin, from Wyoming onto the delta in Mexico, including the states of Colorado, Utah, New Mexico, Arizona, Nevada and California, and Mexican states of Baja and Sonora. In the upper Colorado River basin (UCRB or 'upper basin', defined here as upstream of Lees Ferry, Arizona), dam construction reduced peak flows, changed temperature regimes, and disconnected floodplains from the mainstem. Reduced peak flows caused vegetation encroachment and altered flow regimes, allowing a variety of introduced nonnative fishes to flourish. In this altered environment, recruitment of razorback sucker ceased, resulting in populations solely comprised of older adults. Captures of adult fish in the upper basin rapidly declined as adult mortality was not offset by active recruitment, so some remaining individuals were brought into hatcheries in the 1990s and propagation programs were developed. In the lower Colorado River basin (LCRB or 'lower basin', defined here as downstream of Lees Ferry, Arizona), dam construction had similar effects on habitat. While the reservoirs that resulted from dam construction initially supported some of the largest populations of razorback sucker (>70,000 individuals), these populations gradually declined as nonnative sportfish became abundant in the reservoirs. In response to population declines, razorback sucker were collected in the lower basin in the 1980's to create augmentation programs. The razorback sucker was listed as an endangered species in 1991.

Stocking and reintroduction programs have allowed the species to persist despite a chronic lack of wild recruitment to the adult life stage in most populations. Stocking programs have succeeded in reintroducing adults that survive current ecological conditions and fulfill their ecological role. Stocked razorback sucker successfully reproduce in portions of both basins and have expanded such that populations are now present in much of previously occupied habitat, with the exception of the Gila River system. This SSA evaluates the species in eight geographic areas representing populations including four in the UCRB (Green River, Colorado River, San Juan River and Lake Powell) and four in the LCRB (Lake Mead, Lake Mohave, the Colorado River between Davis and Parker dams [Lake Havasu], and the Colorado River downstream of Parker dam). The Gila River is not evaluated here because a resident population has not been established, despite various stocking efforts.

Species Needs

We divided the life cycle of razorback sucker into five stages including eggs, larvae, juveniles, adults and spawning adults. During each life stage, razorback sucker require certain resource conditions. This SSA summarizes the following eight resource categories, which are considered the most important:

1. Complex lotic and/or lentic habitat available to razorback sucker (*Individual need*)
2. Suitable water temperature and quality (*Individual need*)
3. Variable flow regimes in lotic systems (*Individual need*)
4. Adequate food supply (*Individual need*)
5. Range and connectivity (*Species need*)
6. Population size (*Population need - resiliency*)
7. Multiple interconnected, naturally recruiting, and resilient populations (*Species need - redundancy*)
8. Genetic diversity (*Species need - representation*)

Risks and Conservation Factors

In addition to species needs, the SSA outlines risks (or stressors) and conservation actions that are currently affecting the species condition and are anticipated to do so in the future. Identified risks include climate change, genetic factors (hybridization, reductions in diversity [e.g. inbreeding]), changes in habitat (flow regime/connectivity, land use, habitat availability, water temperature), and nonnative and invasive species (predation, competition and habitat degradation). Overutilization, parasites, diseases, and pollutants were also considered, and although they were considered risks, were determined to be least impactful. Ongoing and future

conservation actions are interrelated and include water management, recovery and conservation program management and funding (including habitat development and management), nonnative species removal, research and monitoring, and hatchery-based augmentation.

Current Condition

The current condition for razorback sucker is determined by considering resource conditions, current risks and management actions, and the demographic response of populations. Resource and demographic conditions were qualitatively assessed by a Science Team comprised of representatives from each state in the species' range and involved federal agencies. Resource conditions were categorized using four levels ranging from high (generally highest condition currently available on the landscape and not representative of pre-human conditions) to extirpated (conditions representative of what would cause species extirpation) with two intermediate categories of medium and low. Interpretations of these levels are presented in Tables 4 and 5 in the text for each resource and demographic category.

Resource conditions in the UCRB are generally categorized as in high to medium condition when examined in isolation of other parameters. The exception is the presence of nonnative fishes in habitat, which is in low condition for most populations. The categorization of nonnative fish presence in habitat is designed to assess the degree to which habitat becomes unavailable to razorback sucker because of predation from or competition with nonnative fishes (Table EX1; details in Table 6 in section 5.1). The Green and Colorado river subbasins are categorized similarly, but flow variability, temperature regulation, and the availability of naturally functioning floodplain habitats are superior in the Green River. The San Juan River has fewer nonnative fish established in the basin, but less variability in habitat, variable flow and less connectivity because of the formation of a waterfall that blocks all upstream movement from Lake Powell into the San Juan. Physical resource conditions in Lake Powell are thought to be sufficient for the species, but large-bodied nonnative predators are abundant in the reservoirs. Lake Powell is the least studied system in the upper basin; substantial uncertainty remains for both physical resource condition and demographic response.

Resource conditions in the LCRB range from high to low when examined in isolation of other parameters, except for nonnative presence in habitat, which was classified as in extirpated condition for all populations except Lake Mead and the Grand Canyon (Table EX1; details in Table 7 in section 5.2). Competition and predation from nonnative predators, which is exacerbated by lack of cover and turbidity, prevents recruitment in all populations except Lake Mead. Flows in the lower basin are modified by water management and hydropower and typically lack flow variability. Contrary to the other systems, the habitat, temperature and food resources in the Grand Canyon were considered low, while nonnative presence in habitat was ranked high as native fish dominate the ecosystem. Habitat, water quality, temperature and food are thought sufficient for all other populations. The geographical ranges in the lower basin reservoirs are large and often include upstream riverine systems. Multiple congregations of fish occur within each population and movement between systems is restricted only by the presence of nonnative predators. The Colorado River population below Parker dam is limited to a section of river where multiple populations have not established. Mainstem dams prevent upstream movement and limit connectivity between populations.

Table EX1. Summary of physical resource current conditions (high condition [generally representing the highest condition currently available] is represented by green, medium condition by yellow, low condition by orange, and extirpated condition [conditions under which extirpation of the species would be expected] is represented by red; condition categories are more explicitly defined in Table 4 in the text). Gray boxes indicate lentic systems where variable flow is not assessed. Lake Powell colors are also shaded in gray to indicate a higher level of uncertainty.

Population	Physical Needs					
	Complex Habitat		Water Quality/Temp	Variable flow (lotic only)	Adequate Food	Range & Connectivity
	Habitat	Nonnative presence in habitat				
Green River Subbasin	Yellow	Orange	Green	Green	Green	Green
Colorado River Subbasin	Yellow	Orange	Yellow	Yellow	Green	Green
San Juan River Subbasin	Yellow	Yellow	Yellow	Yellow	Green	Yellow
Lake Powell	Gray	Gray	Gray	Gray	Gray	Gray
Lake Mead	Green	Orange	Green	Gray	Green	Yellow
Grand Canyon	Orange	Green	Yellow	Orange	Orange	Yellow
Lake Mohave	Yellow	Red	Green	Gray	Green	Yellow
Lake Havasu	Green	Red	Green	Orange	Green	Yellow
Colorado Mainstem Below Parker Dam	Yellow	Red	Green	Orange	Green	Orange

Current demographic conditions for the UCRB and LCRB are shown below (Table EX2; details in Tables 12 and 13 in section 5.3). The Green River subbasin currently holds the largest population of adult razorback sucker, which consists almost entirely of hatchery-reared individuals. Adults spawn annually at multiple locations and juvenile recruitment has been documented in floodplain wetlands in the Green River subbasin in each of the past five years. However, recruitment to the adult life-stage is rare, resulting in a low condition for that category. The adult razorback sucker population in the Colorado River subbasin has been increasing over the last decade through stocking efforts. Spawning and larval presence have been documented in the mainstem Colorado and tributaries above the confluence with the Green River. Untagged juveniles and adults have rarely been encountered, indicating that recruitment is not commonly occurring. Because recruitment in both systems is uncommon, monitoring efforts are not directed at this life stage. In both the Green River and Colorado River subbasin populations, a lack of recruitment is considered a result of nonnative predation and lack of access to rearing habitat. The San Juan River subbasin population has been consistent in size, but also consists almost entirely of hatchery-reared individuals. Spawning and larval production has occurred annually for the last 20 years, but there are indications that only a small percentage of the population is spawning. Juvenile recruitment has rarely been documented. A large population of nonnative channel catfish exists in the San Juan subbasin, but other large-bodied predators have not become established. A waterfall has recently formed on the San Juan River preventing upstream movement of fish from Lake Powell into the San Juan subbasin. The Lake Powell population of

razorback sucker is not stocked directly but is comprised of individuals stocked in the other three river subbasins. Additional research is needed to determine the source of high levels (19% or more) of untagged adults in Lake Powell. Despite the presence of adult razorback sucker across the UCRB, the populations are not self-sustaining and are dependent on continued stocking effort. In the absence of wild recruitment or continued stocking efforts, the populations would decline to extirpation.

Table EX2. Summary of demographic current conditions (high condition [generally representing the highest condition currently available] is represented by green, medium condition by yellow, low condition by orange, and extirpated condition [conditions under which extirpation of the species would be expected] is represented by red; condition categories are more explicitly defined in Table 5 in the text). Gray boxes indicate lentic systems where variable flow is not assessed. Lake Powell colors are also shaded in gray to indicate a higher level of uncertainty.

Population	Demographics					
	Adult population	Spawning and larval Presence	Recruitment	Dependence on Stocking	Genetic integrity	Population Stability
Green River Subbasin	Green	Green	Orange	Orange	Yellow	Orange
Colorado River Subbasin	Green	Yellow	Red	Orange	Yellow	Orange
San Juan River Subbasin	Yellow	Yellow	Red	Orange	Yellow	Orange
Lake Powell	Gray	Gray	Gray	Gray	Gray	Gray
Lake Mead (and Grand Canyon)	Orange	Green	Green	Green	Yellow	Green
Lake Mohave	Yellow	Green	Red	Orange	Green	Red
Lake Havasu	Yellow	Yellow	Red	Orange	Green	Red
Colorado Mainstem Below Parker Dam	Red	Orange	Red	Red	Yellow	Red

In the LCRB, razorback sucker are actively recruiting in Lake Mead despite abundant nonnative fishes and lack of active management, leading to high condition scores for most demographic categories (Table EX2; details in Table 13 in section 5.3). The razorback sucker population in Lake Mead is small (approximately 500 adults) which is not thought to be sufficient to maintain genetic integrity long-term prompting a lower rating in that category. The three remaining razorback sucker populations (Lake Mohave, Lake Havasu, and below Parker Dam) in the LCRB are managed using stocking to maintain populations in the presence of nonnative predators. Larvae are collected annually from Lake Mohave (which also serves as a genetic refuge), reared in off-channel ponds or hatchery facilities and reintroduced as adults. Lake Havasu and the Colorado River below Parker Dam are stocked using traditional methods. These are successful strategies, however without continued reintroduction, these razorback sucker populations would become extirpated. The Colorado River between Davis and Parker dams (Lake Havasu) is home

to a repatriated population of razorback sucker and currently contains the largest population in the lower basin. The mainstem Colorado River below Parker Dam is actively stocked, but survival is low, resulting in populations too small to measure.

Current Viability

Resiliency

We use summaries of current condition to assess resiliency in each population. To summarize current condition, we averaged the classifications presented above using values of 3 for high condition, 2 for medium condition, 1 for low condition and 0 for extirpated condition¹. When all habitat and demographic conditions were averaged for each population (Table EX1 and EX2), population resiliency is classified as medium (scores of 1.51 to 2.25) for all populations with the exception of the Colorado River below Parker dam, which was categorized as low (between 0.76 and 1.5). The classifications represent our understanding of the range of physical and demographic conditions currently found on the landscape. When only demographic conditions were used, Lake Mead was classified as high, the Green River subbasin was classified as medium, Colorado and San Juan river subbasins, Lake Powell, Lake Mohave, and Lake Havasu were classified as low and the Colorado River below Parker dam was classified as extirpated (Figure EX1).

We use averages of only demographic conditions to describe resiliency. Lake Mead has the highest resiliency in the system as the only population in which razorback sucker regularly complete all life stages despite abundant nonnative fishes, proving resiliency in the face of threats; however, the population size is small, causing genetic concerns that may require future management intervention. The high categorization is not meant to be representative of pre-anthropogenic conditions, to imply that conditions cannot improve or that the resiliency currently on the landscape is independent of management efforts. Razorback sucker across the Colorado River basin are actively managed and the resiliency presented here is dependent on those actions. The Green River is in the medium category because of resiliency in certain life stages (e.g. large population size, high spawning and larval presence and consistent recruitment to the juvenile stage with management). Populations are present, spawning and migrating in seven of the eight populations, though many at abundance levels dramatically lower than they were historically. Without continued management efforts, all populations would eventually decline to an extirpated condition and those in low or extirpated condition would decline more rapidly.

¹ Summary scores for resiliency are colored using the following matrix: 0-0.75 represents extirpated, 0.76-1.5 represents low, 1.51-2.25 represents medium and 2.26-3 represents high.

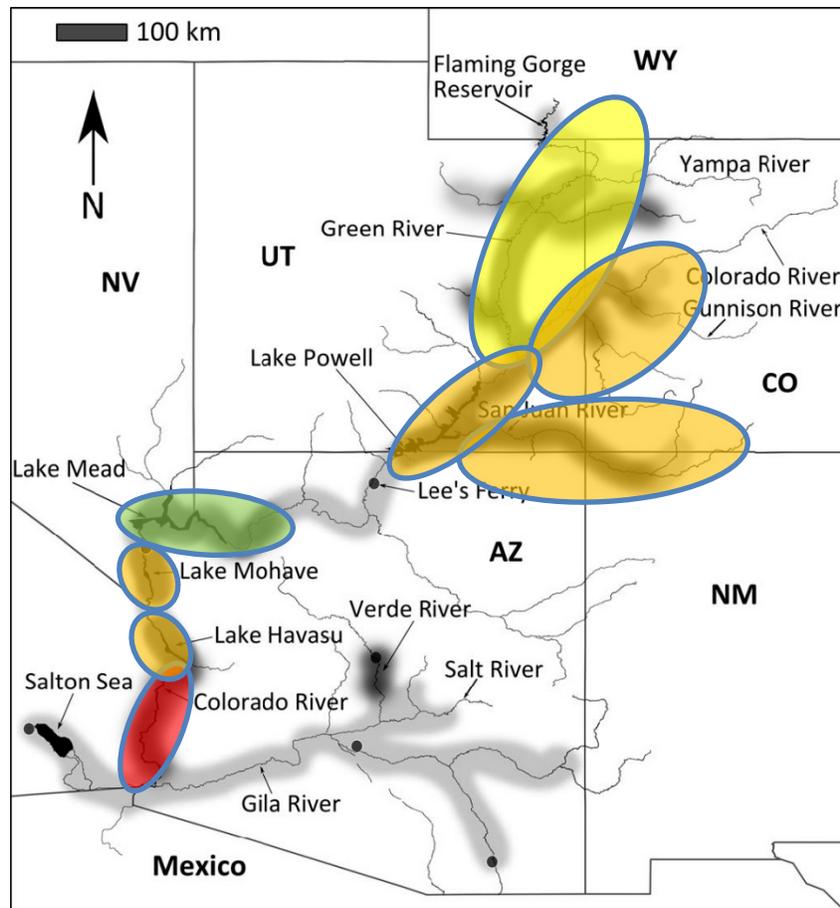


Figure EX1. Historical (light gray highlight) and current (dark gray highlight) distribution of the razorback sucker in the Colorado River basin with populations colored with the average of current demographic condition. High condition is indicated by green, medium condition is indicated by yellow, low condition is indicated by orange, and extirpated condition is indicated by red.

Representation

Razorback sucker have shown a high degree of plasticity in their ability to inhabit both lotic and lentic habitats and survive a wide range of environmental conditions. After populations were dramatically reduced in the upper basin, stocked individuals have shown an ability to spawn and migrate. Genetics of upper and lower basin populations are managed and therefore genetic diversity has been maintained. Lower basin populations, especially in Lake Mohave, show higher genetic diversity and less relatedness than upper basin populations (Dowling *et al.* 2012). Some hybridization occurs with other native and nonnative suckers, but currently at low levels. Genetic representation both within and among populations is high, but genetic adaptability will remain low as long as stocking is required to maintain populations as adaptive genetic traits are not passed from one generation to another through natural recruitment.

Redundancy

Razorback sucker are widely distributed across the Colorado River basin, occurring in multiple habitat types and likely to withstand local or even regional catastrophes. The high genetic

diversity present in Lake Mohave is distributed throughout the lower basin through larval collections and subsequent stocking, providing redundancy. Like resiliency, this redundancy is based on management actions, as most populations contain almost exclusively stocked individuals. Recolonization of catastrophically affected areas would like occur through direct or indirect stocking efforts. Stocked adults commonly migrate between populations in the upper basin. In the Green and Colorado river subbasins, most major barriers have been removed or their effects ameliorated by fish passage structures. Barriers to upstream movement remain in the San Juan river subbasin, although fish stocked in the San Juan have been documented in Lake Powell and the Green and Colorado rivers. Stocked individuals are routinely documented to move long distances expanding into appropriate habitat across the basin. Razorback sucker in lower basin populations congregate in specific inflow or spawning areas around the lake, and have been shown to migrate between those areas. However, upstream movement is blocked between populations. Should an entire population be eliminated, management actions would need to support reestablishment of the species in those areas.

Evaluation of Future Condition

The future condition of the razorback sucker is derived by considering future resource conditions for each population under five scenarios.

To define the bounds of future conditions, a Delphi process was used to survey a group of species experts to rank the most impactful risks and conservation actions over the next 30- and 100-year periods. Three factors were weighted highest for the 30-year period: nonnative predation, flow regime and water management. A second tier included conservation and recovery efforts: program funding, augmentation, nonnative removal, and research and monitoring. The results were similar over the 100-year period, but climate change was predicted to be of greater concern than it was over the 30-year period. For this SSA, the future condition scenarios are evaluated at a timeframe of 30 years, which corresponds to approximately three razorback sucker generation times.

Based on these results and the substantial impacts of management on razorback sucker, the Science Team assessed future condition scenarios based on the effectiveness of management actions. The scenarios include two worst-case scenarios representing least successful conservation and augmentation programs (scenarios 1 and 2), a status quo (scenario 3), and two best-case scenarios representing the possibility of establishing naturally recruiting populations (scenarios 4 and 5). All scenarios assume higher water temperatures and lower water availability in the system as a whole. For each of the potential future scenarios, the Science Team members individually predicted the overall effect of a scenario within each population using best professional judgement as described in section 6.2. Predictions of future condition of the species demographic needs were averaged across needs and across participants and are presented in Figure EX2, with details provided in Figures 33 – 42 and in sections 6.2.1-6.2.5.

- Scenario 1 – Recovery and conservation actions for razorback sucker are reduced to minimal levels because of funding reductions or program expiration. This scenario assumes elimination of some active and adaptive management actions, and reduction in voluntary management actions for the species, such that many actions are no longer in place to mitigate

decreased water availability, future water development, or nonnative fish pressures. This scenario assumes dramatic downscaling of upper basin programs but assumes funding and continuation of lower basin programs through the timeframe(s) considered.

- Upper basin populations – management of streams flows would decline, nonnative fish populations expand; adult population of razorback sucker would decline to extirpation at varying rates.
 - Lower basin populations – habitat and flow conditions would like remain similar to current condition, adaptive management may slow or cease, causing decreases in all populations except Lake Mead.
 - Resiliency, redundancy and representation all decline to extirpation.
 - Participants predicted likelihood of this scenario to be unlikely in the 30-year period, but about as likely as not over 100 years.
- Scenario 2 – Recovery actions continue at levels thought to be beneficial to the species as are currently in place, but augmentation efforts are less effective than currently observed which results in a reduction in survival of stocked fish. Overall effectiveness of recovery actions is below current success levels.
 - Upper basin populations – management of stream flows, wetlands, screens, and nonnative fishes would continue; reduced survival in stocked fish would prompt declines in all populations; the Colorado and San Juan river subbasins would likely reach extirpation, the Green River subbasin and Lake Powell would fall at least to low condition.
 - Lower basin populations – lack of effective augmentation would cause extirpated conditions in Lake Mohave and the Colorado River below Parker dam, threatening representation. The populations in lakes Mead and Havasu would decline, with the Havasu population reaching low condition.
 - Declines expected in resiliency, redundancy and representation.
 - Participants predicted likelihood of this scenario to be about as likely as not in the 30-year period, and likely over 100 years.
- Scenario 3 (status quo) – Recovery and conservation actions continue at levels thought to be beneficial to the species (including legally required actions and adaptive/voluntary efforts currently in place) and are effective at reducing some threats. This scenario represents continuation of the status quo and the effectiveness of recovery actions as we currently understand them.
 - Upper basin populations – increases in condition are expected in all populations, but remaining threats are persistent, limiting possible gains. Minimal recruitment is expected in some populations, but not enough to exceed adult mortality.
 - Lower basin population - small increases in condition are expected, potentially from improved stocking success. Dramatic gains are prevented by nonnative species remaining abundant in all populations, limiting effective population size. Wild recruitment is not expected.
 - Improvements in resiliency are expected in some populations.
 - Participants predicted likelihood of this scenario to be very likely in the 30-year period, and likely over 100 years.

-
- Scenario 4 – Recovery actions continue at levels thought to be beneficial to the species (including legally required actions and adaptive/voluntary efforts currently in place) and are effective at reducing threats to a level supporting active recruitment, more than is currently realized. This scenario assumes reduction of current stressor(s) affecting populations.
 - Upper basin populations – assumes effective management of multiple floodplain wetlands or an increase in effectiveness of nonnative fish controls, producing year classes of wild fish sufficient to recruit. Increases in condition are expected in all upper basin populations driven by recruitment success, resulting in reduced stocking levels.
 - Lower basin populations – assumes creation of off channel wetlands or methods to protect razorback sucker habitat from nonnative fish predation in reservoirs, resulting in an increase in recruitment in Lake Mohave or Lake Havasu, but not at levels sufficient to reduce stocking efforts.
 - Resiliency of populations would increase, coupled in increases in redundancy.
 - Participants predicted likelihood of this scenario to be unlikely in the 30-year and 100-year periods.

 - Scenario 5 – Improved recovery actions support wild populations of razorback sucker (includes legally required actions plus adaptive and voluntary efforts currently in place) and are effective at reducing most threats in the system. This scenario assumes improved effectiveness of recovery actions (effective basin wide nonnative fish suppression, rearing habitat management) to a level where recruitment completely sustains the populations.
 - Upper basin populations – all populations reach high condition in this scenario as a result of nonnative fish removal (instead of control) and establishment of sufficient juvenile habitat.
 - Lower basin populations – all populations reach medium condition in the scenario as a result of removal/control of at least some nonnative predators in reservoirs.
 - Resiliency would dramatically improve in all populations and redundancy would improve as populations grow. Representation would no longer be management based.
 - Participants predicted likelihood of this scenario to be very unlikely in the 30-year period and unlikely over 100 years.

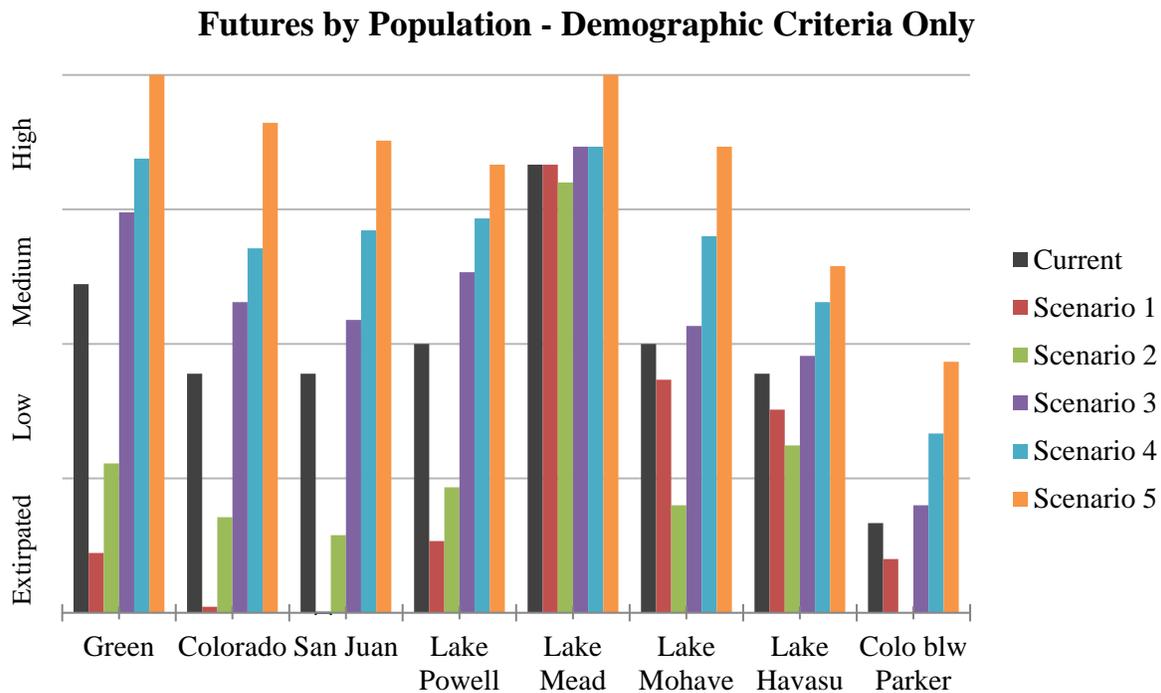


Figure EX2. Predicted response in demographic needs for razorback sucker under future scenarios 1-5.

Future Viability

The results of the management-based future scenarios predict future conditions ranging from restoration of populations to a high condition to returning to the low condition seen in the last half century (Figure EX3). Multiple management actions have been taken to date to improve razorback sucker populations from previous low levels in the UCRB. Flow recommendations have been developed and implemented to ensure flows mimic the natural hydrograph to the extent possible. Fish screens and fish passages have been constructed to prevent entrainment in canals and allow for migration of native species across the basin. Management of floodplain wetlands has produced young-of-year razorback documented to survive their first year of life. Stocking of razorback sucker and removal of nonnative fishes occur annually. These management actions have improved resiliency of populations, created redundancy and maintained representation. Continuation of these management actions is likely to continue the gains in resiliency while cessation of management actions is likely to threaten resiliency, redundancy and representation.

The management-based future scenario results predict a much narrower range of future conditions in the LCRB than in the UCRB populations, mostly because of the dominance of nonnative predators in the system. Management actions include collection of larvae and management of off channel ponds for growth and stocking throughout the system, neither of which are designed to improve resiliency but do actively manage redundancy and representation of the species. Nonnative predators are not managed in most LCRB habitats. Because of these constraints, only under scenario 5 is a return of demographic conditions to a high category

predicted in two populations. The most dramatic losses in resiliency in the lower basin are predicted in scenario 2 due to the reduced effectiveness of stocking, as stocking is the primary tool used to maintain populations on the landscape.

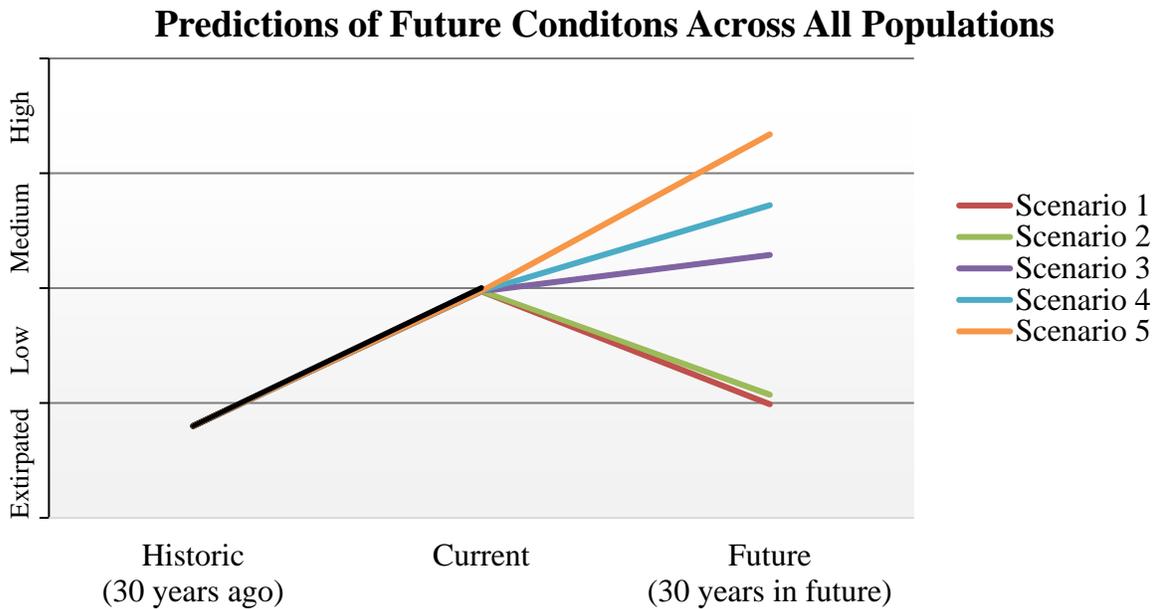


Figure EX3. Prediction of razorback sucker population response under the five future scenarios for all populations in relation to historic conditions at time of listing (~30 years ago).

When both basins are combined, predicted future condition ranges from high to low, with a larger distribution of values in the upper basin influencing the overall range (Figure EX3). The current condition of razorback sucker has been driven by the conservation actions that have occurred over the last 30 years, and it is likely that the population condition in the future will also be driven by those management actions. Should management actions continue and be successful, improvements are expected in resiliency. Should management actions cease, resiliency, and therefore redundancy and representation of razorback sucker are likely to decline.

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ACRONYMS AND ABBREVIATIONS

BO	Biological Opinion
CRI	Colorado River Inflow Area of Lake Mead
cfs	cubic feet per second
EIS	Environmental Impact Statement
ESA	Endangered Species Act
HCP	Habitat Conservation Plan
LCR	lower Colorado River
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
LCRB	lower Colorado River basin
LGC	lower Grand Canyon
LM	Lake Mead
LTSP	Larval Trigger Study Plan
MCA	multicriteria analysis
mg/L	milligrams per liter
µS/L	microsiemens per liter
NDOW	Nevada Department of Wildlife
NPS	U.S. National Park Service
PBO	Programmatic Biological Opinion
PCR	Colorado River arm of Lake Powell
PIT	passive integrated transponder
PSJ	San Juan River arm of Lake Powell
Reclamation	U.S. Bureau of Reclamation
ROD	Record of Decision
SJRIP	San Juan River Basin Recovery Implementation Program
SL	standard length
SNARRC	Southwestern Native Aquatic Resources and Recovery Center
SSA	Species Status Assessment
TL	total length

UCRB	upper Colorado River basin
UCREFRP	Upper Colorado River Endangered Fish Recovery Program
USFWS	U.S. Fish and Wildlife Service
USGS	United States Geological Survey

1 INTRODUCTION

1.1 Overview and Report Organization

This Species Status Assessment (SSA) report provides an assessment of the biological status of the federally endangered razorback sucker *Xyrauchen texanus*. Based on the best available scientific information, this SSA may be used by the U.S. Fish and Wildlife Service (USFWS) to inform Endangered Species Act (ESA)-related decisions about the species. The goal of the SSA is to provide a clear characterization of species viability, including controlling factors, species risks, and key uncertainties. This SSA does not replace or supplant species recovery plans or 5-year status reviews; it is intended to be a living document that is updated as new information about the status of razorback sucker is obtained (D. R. Smith *et al.* 2018).

This SSA is organized according to the following sections:

- 1.0 Introduction: provides an overview of the SSA framework and this document.
- 2.0 Species Overview: describes the species and taxonomy, listing status, range and distribution, and life history.
- 3.0 Species Needs: describes the resource needs of individuals and populations and aspects of the environment that are considered important to species viability.
- 4.0 Risk and Conservation factors: describes the risks and conservation measures likely to affect the species habitat and demographics.
- 5.0 Current Condition: describes current conditions of resources and species demographics by population.
- 6.0 Future Condition: describes the species' response to plausible future scenarios to provide the information necessary to assess future viability.

Throughout the assessment, the principles of resiliency, redundancy, and representation are used to ensure the SSA is biologically sound and that species conservation is fully considered (D. R. Smith *et al.* 2018):

- Resiliency describes the ability of a species to withstand stochasticity—either environmental or demographic. Resiliency can be measured by the abundance, survival and/or growth rate of a population, and may be influenced by connectivity amongst populations. Resiliency can be assessed at either an individual or a population level.
- Redundancy describes the ability of a species to withstand catastrophic events by spreading the risk among populations. Redundancy is characterized by having multiple, resilient populations distributed across the range of the species. It can be measured by the number of populations, their resiliency, and the spatial scale of their distribution and degree of connectivity.

- Representation describes the ability of a species to adapt to changing environmental conditions over time. It is characterized by the breadth of genetic and environmental diversity within and among populations. Measures may include the number of varied niches occupied, genetic diversity, and heterozygosity, and/or alleles per locus. This principle involves the relationship between a species' life history and its genetic and ecological diversity, and the subsequent influence on the species' ability to adapt to changing environmental conditions.

1.2 Species Status Assessment (SSA) Framework

An SSA provides a consistent, conservation-focused, and scientifically sound assessment of the biological status of a species (D. R. Smith *et al.* 2018). The SSA entails the following assessment stages (Figure 1):

1. **Species Needs:** The first stage explores and describes the species' life history, including trophic niches, reproductive strategies, biological interactions and habitat requirements to determine how individuals at each stage survive and reproduce. The SSA identifies significant ecological, genetic or life history variation informed by historical as well as present distribution.
2. **Species Current Condition:** The second stage describes the current condition of the species' habitat, demographics and distribution and provides probable explanations for past and ongoing changes in abundance, distribution and diversity.
3. **Species Future Condition:** The last stage assesses the status of the species by projecting the species' response to probable future environmental condition scenarios. This stage describes a species' ability to sustain populations in the wild using a biologically meaningful period that considers generation time and longevity.

Species Status Assessment Framework

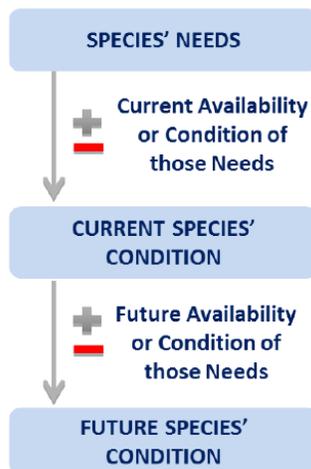


Figure 1. SSA Framework's three basic stages from the SSA Framework (U.S. Fish and Wildlife Service 2016).

Conducting an SSA involves compiling and analyzing the best available scientific information for the species. The SSA report is a stand-alone, science-based product independent of the application of policy or regulation. It provides foundational biological information, articulates key uncertainties, and ultimately characterizes the species' current and potential future condition and viability under various scenarios and timeframes (D. R. Smith *et al.* 2018).

1.3 Contributions from Experts

This SSA was developed in two phases with significant contributions from scientists and researchers who contribute to programs throughout the basins. During the first phase, 56 of 87 invited biologists participated in some part the Delphi process, which assessed the greatest threats to the viability of razorback sucker over multiple timeframes. Forty-seven biologists completed all surveys. During the second phase, a Science Team (made up of state and federal representatives from programs in both basins) qualified and categorized current condition and developed future scenarios based on the information provided in the Delphi process. The Science Team assessed the threats identified in the Delphi process and used best professional judgement to predict how those threats are likely to impact the species over a foreseeable future.

2 SPECIES OVERVIEW

2.1 Description and Taxonomy

Xyrauchen is one of several monotypic genera of the family Catostomidae. Razorback sucker was originally described as *Catostomus texanus* (Abbott 1861; Bestgen 1990; U.S. Fish and Wildlife Service 2002). Subsequent reclassifications were made by Kirsch (1889), who assigned it to the genus *Xyrauchen* due to the species' unique keel feature, and Jordan (1891), and later by Hubbs and Miller (1953), LaRivers (1962), and Minckley (1973). The species name *texanus* is based on a misunderstanding that the earliest specimens erroneously originated from the Colorado River in Texas (Marsh *et al.* 2015).

Meristic and morphological descriptions of the species, as cited in Bestgen (1990), follow below (Abbott 1861; Ellis 1914; Hubbs and Miller 1953; W. L. Minckley 1973; Moyle 1976; McAda and Wydoski 1980; Snyder and Muth 1990):

The razorback sucker is distinguishable from all other catostomids by its unique, bony, dorsal keel abruptly rising posterior of the head. The body shape is elongate, robust, and somewhat laterally compressed. The caudal peduncle tends to be short and deep. An enlargement of the interneural bones forms the distinctive razor-like keel, providing basis for the common name, razorback sucker. The moderate-sized mouth has a clefted lower lip, and lateral margins of the lips are continuous and rounded. Razorback sucker have elongated heads with a flattened dorsal surface and well-developed fontanelle. There are usually 14–15 primary dorsal fin rays, seven primary anal fin rays, 45–47 vertebrae, 68–87 scales in the lateral series, with 44–50 gill rakers on the first arch. Body coloration is dark brown to olivaceous on the upper dorso-lateral surfaces and ranges from yellow to white on the lower ventro-lateral surfaces. Adults can reach up to 1,000 mm total length (TL) and weigh 5–6 kg, but they are more typically found within the 400–700 mm TL range, weighing less than 3 kg. During spawning, razorback sucker are sexually dimorphic, with breeding males showing bright yellow and orange laterally and ventrally, dark dorsal surfaces, and tuberculation, especially on the anal and caudal fins, and females exhibiting a distended genital papillus.

Furthermore, based on skeletal measurements, razorback sucker morphology is heavily ossified, thickened, and likely adapted to the strong river currents historically occupied by this species (Eastman 1980).



Figure 2. Razorback sucker, photo provided by Melanie Fisher.

2.2 Listing Status and Recovery Planning

The razorback sucker was first proposed for listing as a threatened species on April 24, 1978 (43 FR 17375). The proposal to list as threatened was withdrawn on May 27, 1980 (45 FR 35410) to comply with provisions of the 1978 amendments to the ESA, which required the USFWS to include consideration of designating critical habitat in the listing of a species and to complete the listing process within 2 years after the date of a proposed rule or withdraw the proposal from further consideration. In this case, the USFWS did not complete the listing process within the 2-year deadline. On March 15, 1989, the USFWS received a petition to list the razorback sucker as endangered. Listing documents cited a lack of recruitment, dwindling numbers of adults, and occupation of only 25% of historical range as signs of endangerment and cited altered flow regimes, habitat dewatering, and negative interactions with nonnative fishes as factors affecting the species. The USFWS made a ruling in June 1989 to list the species as endangered and subsequently published a notice in the Federal Register on August 15, 1989. The proposed rule to list the species as endangered was published on May 22, 1990 (55 FR 21154). The final rule listing the razorback sucker as an endangered species was published on October 23, 1991 (56 FR 54957).

Subsequently, critical habitat was designated as 2,776 kilometers (km) of the Colorado River basin on March 21, 1994 (59 FR 13374). This was composed of 1,519 km in the upper Colorado River basin (UCRB or “upper basin”) and 1,255 km in the lower Colorado River basin (LCRB or “lower basin”) (Figure 3). The species was listed prior to the 1996 Policy Regarding the Recognition of Distinct Vertebrate Population Segments (61 FR 4721-4725), and there are no

distinct population segments designated or proposed for the species (U.S. Fish and Wildlife Service 1998; U.S. Fish and Wildlife Service 2012).

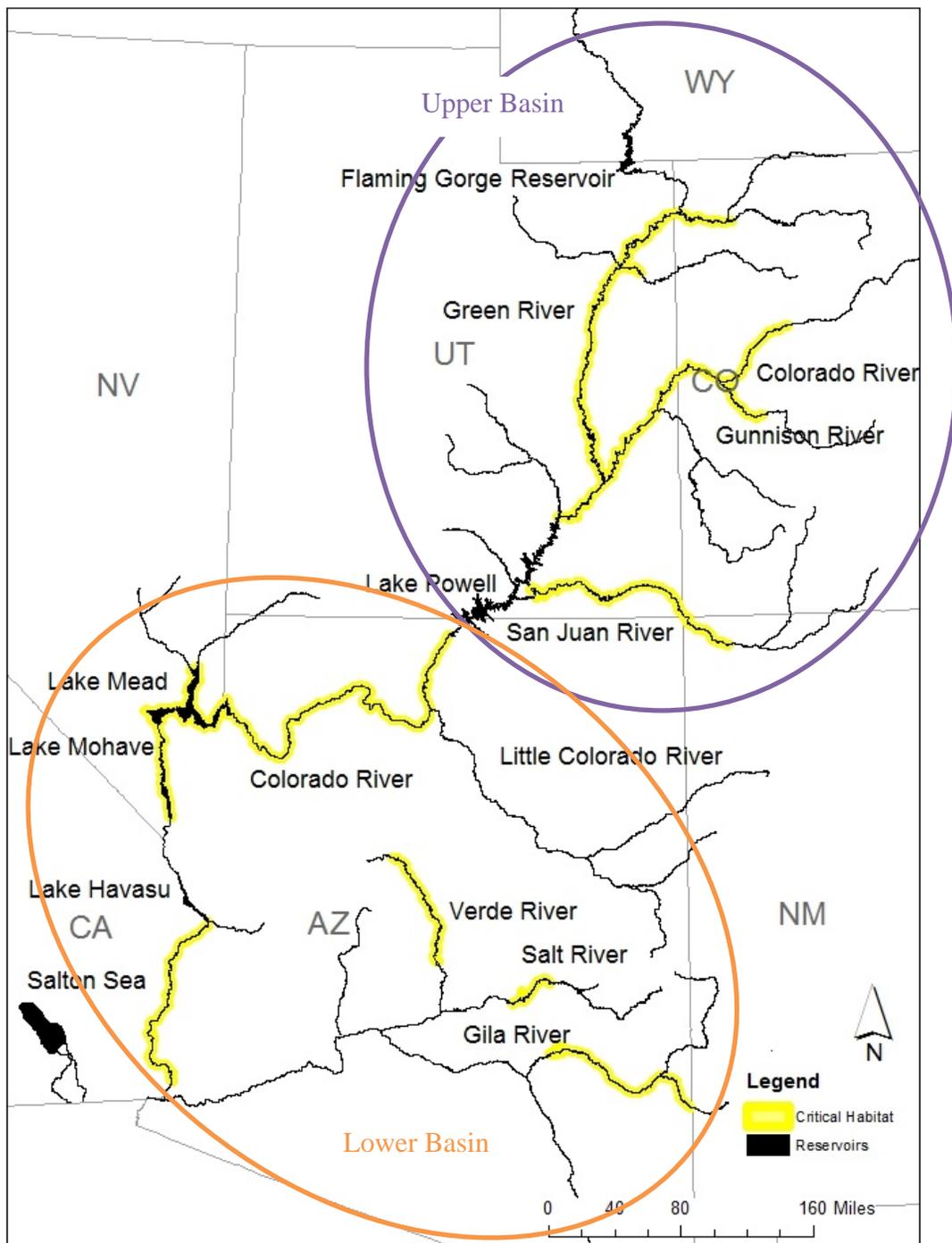


Figure 3. Critical habitat designated for the razorback sucker in 1994 (yellow highlight) and general areas defined as upper and lower basins.

The initial recovery plan for the razorback sucker was completed in 1998 (U.S. Fish and Wildlife Service 1998). Recovery goals that amended and supplemented the 1998 plan were approved

August 1, 2002 (U.S. Fish and Wildlife Service 2002). Downlisting criteria required genetically and demographically viable, self-sustaining razorback sucker populations in the Green River subbasin and either the Colorado River subbasin or the San Juan River subbasin, a genetic refuge in Lake Mohave, and two genetically and demographically viable, self-sustaining populations in the lower basin. Delisting required population improvements for three consecutive years post-downlisting. The last 5-year review for razorback sucker was completed in 2012 (U.S. Fish and Wildlife Service 2012). The 5-year review noted some improvements in demographic criteria, but most criteria had not been met; species status remained endangered. The threat removal criteria showed much greater improvements especially in relation to increased floodplain habitat and removal of fish passage blockages; implementation of flow recommendations and addition of fish screens were indicated as partially met (U.S. Fish and Wildlife Service 2012). The 5-year review indicated that the 2002 recovery goals needed to be updated with new information, especially in relation to the fact that populations are likely to fluctuate over time and not continue on an increasing trend in all years.

2.3 Historical Range and Distribution

Razorback sucker are endemic to the Colorado River Basin, which encompasses parts of seven western states including Arizona, California, Colorado, Nevada, New Mexico, Utah and Wyoming as well as parts of Sonora and Baja California, Mexico. The upper and lower basins are split at Lees Ferry, Arizona, which is downstream from Glen Canyon Dam. Glen Canyon Dam, which was constructed in 1957-1964, provides physical separation between the UCRB and LCRB. Razorback sucker were widespread and common throughout the larger rivers of the entire basin (W. L. Minckley *et al.* 1991; Marsh 1996; Marsh 1996) (Figure 4) with particularly high razorback sucker abundance in the LCRB near Yuma, Arizona (Gilbert and Scofield 1898). Razorback sucker are thought to have been uncommon in turbulent, canyon-bound reaches, with robust populations typically being found in calm, flatwater river reaches (Tyus 1987; Lanigan and Tyus 1989; Bestgen 1990). Historical populations were affected by the construction of multiple in-stream impoundments in the early-to-mid 1900s, which changed riverine conditions. Razorback sucker has persisted in some resulting reservoirs but been extirpated in others.

2.3.1 Upper Colorado River Basin

Historically, razorback sucker were widespread in the UCRB in warm-water stream reaches (Bestgen 1990). By the time endangered fish studies began around 1980, populations were apparently reduced from historical levels (Bestgen 1990). The largest numbers of razorback sucker in the Upper Colorado River Basin were found in low gradient, flat-water reaches of the middle Green River between the Duchesne River and the Yampa River and in the Colorado River near Grand Junction (Tyus 1987; Bestgen 1990; Muth *et al.* 2000). In the upper Colorado River subbasin, the number of razorback sucker captured decreased dramatically after 1974. At that time the wild population was considered extirpated from the Gunnison River (Burdick and Bonar 1997) and there were only a few scattered adults in the mainstem Colorado River (D. B. Osmundson and Kaeding 1989b). Between 1984 and 1990, only 12 individuals were captured in the Colorado River in the Grand Valley (an area encompassing Grand Junction, Colorado) despite intensive collection efforts (D. B. Osmundson and Kaeding 1991). No young razorback sucker were captured anywhere in the upper Colorado River subbasin from the mid-1960s to

about 1990 (D. B. Osmundson and Kaeding 1991). The last wild razorback sucker in the UCRB was captured in the Colorado River in 1995.

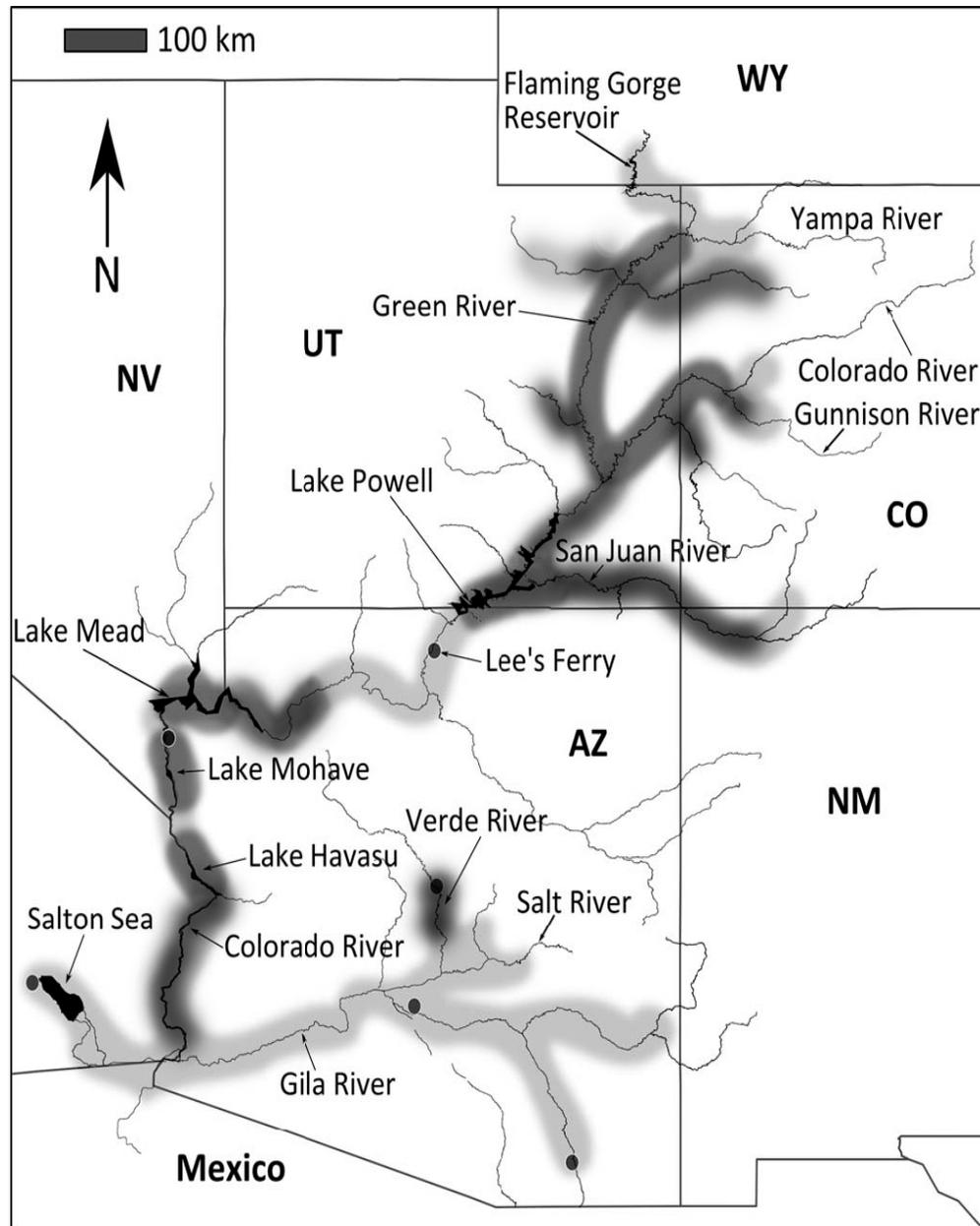


Figure 4. Historical (light gray highlights) and current (dark gray highlights) distribution of the razorback sucker in the Colorado River basin (points are archeological sites; dark gray portions of map were modified from Marsh *et al.* 2015). Reservoir and lake boundaries appear as solid black.

Bestgen *et al.* (2012) reported that wild razorback sucker were extirpated from the San Juan River subbasin, but that stocked hatchery-produced fish were surviving and reproducing annually. Anecdotal reports from the late 1800s document razorback sucker occurring in the Animas River as far upstream as Durango, Colorado (Jordan 1891), although there are no known

voucher specimens to confirm this observation. The first razorback sucker specimens were collected in the San Juan River in 1976, when two adults were collected in an irrigation pond near Bluff, Utah (VTN Consolidated, Inc., and Museum of Northern Arizona, 1978, as cited in (Farrington *et al.* 2015). No wild razorback sucker were found during the 7-year research period (1991–1997) of the San Juan River Basin Recovery Implementation Program (SJRIP) (Holden 1999).

Razorback sucker has recently been the subject of various investigations in Lake Powell. Little is known about historical status of rare fish in the Lake Powell as survey and monitoring results were limited (Bestgen 1990). Despite limited sampling, razorback sucker were known to have inhabited the San Juan River Arm of Lake Powell since 1982 (Francis *et al.* 2015).

2.3.2 Lower Colorado River Basin

The trend of declining razorback sucker populations observed in the Colorado River were also occurring in Lake Mead after Hoover Dam was completed in 1935. Razorback sucker numbers, initially high in Lake Mead, decreased noticeably in the 1970s, and no razorback sucker were collected during the 1980s (W. L. Minckley 1973; T. McCall 1980; W. L. Minckley *et al.* 1991; Sjoberg 1995). However, in the early 1990s, Nevada Department of Wildlife (NDOW) personnel confirmed razorback sucker was still present in two localized areas of Lake Mead: Las Vegas Bay and Echo Bay. Further explorations led to the discovery of several groups of wild fish spawning and recruiting in the reservoir. These groups currently represent the only known wild population of razorback sucker in the Colorado River basin to consistently demonstrate natural recruitment (Shattuck *et al.* 2011; Albrecht *et al.* 2013a; Albrecht *et al.* 2013b; Albrecht, Shattuck *et al.* 2014; Albrecht, Kegerries *et al.* 2014; Shattuck and Albrecht 2014; Kegerries, Albrecht *et al.* 2015; Mohn *et al.* 2015; Mohn *et al.* 2017).

Ten historical records exist for the presence of razorback sucker between Glen Canyon Dam and the upper extent of the inflows of Lake Mead between 1944 and 1990 (Valdez 1996; Valdez and Carothers 1998). Razorback sucker were detected in 1990 at the confluence of the Little Colorado River, but they were thought to be functionally extirpated in the Grand Canyon (Clarkson and Childs 2000). Limited information is available regarding the historical spawning activities of razorback sucker in the Grand Canyon (Albrecht *et al.* 2014), but presumptive razorback sucker larvae were found in the canyon in 1998 (M. R. Douglas and Douglas 2000). In 2012, the first adult razorback sucker was captured in Spencer Canyon in over 20 years (Bunch *et al.* 2012). Recently, both larvae and adult razorback sucker have been discovered utilizing both the lower Grand Canyon and the inflows to Lake Mead; razorback sucker have been documented to be spawning at least 161 river kilometers from Lake Mead consistently between 2014 and 2017. (Albrecht *et al.* 2014; Kegerries, Albrecht, Gilbert *et al.* 2017; Kegerries, Albrecht, Rogers *et al.* 2017).

The largest reservoir population of razorback sucker, estimated at 75,000 in the 1980s, occurred in Lake Mohave, Arizona and Nevada, but at present, no wild fish remain because of lack of recruitment (Marsh *et al.* 2003; Marsh *et al.* 2005; Marsh *et al.* 2015). However, Lake Mohave remains an actively managed and important genetic refuge for the species where larvae are collected, reared in the hatchery, and released back into the reservoir at larger sizes to improve

survival as little to no natural recruitment occurs as a result of predation (Marsh *et al.* 2003; Marsh *et al.* 2005; Dowling *et al.* 2014; Marsh *et al.* 2015). Frequent razorback sucker were also often reported in the riverine LCRB downstream of Lake Mohave from the early 1940s through early 1980s (W. L. Minckley 1983; Marsh and Minckley 1989).

The Gila River system encompasses the Verde, Gila and Salt rivers and their tributaries. Razorback sucker historically occupied all larger streams in the Gila River Basin including the Salt, Verde, and Gila Rivers (W. L. Minckley and Deacon 1968). By the 1970s, the species was extirpated from the basin and by 1981 efforts to reestablish razorback suckers had begun. Between 1981 and 1990, more than 11 million hatchery-produced razorback sucker were released at 57 sites into historic habitat in the Gila system where the natural population had been extirpated (Hendrickson 1994). Stockings during this period consisted of mostly fry and fingerlings, but were stocked at larger sizes (up to 300 mm) towards the end of that time period. Low short-term survival and no long-term survival was reported from these releases, primarily because of predation by nonnative fishes, including flathead catfish *Pylodictis olivaris*. In 1991, razorback sucker were stocked at lengths >300 mm to reduce predation. From 1991 through 2003, 24,915 larger sized razorback suckers were stocked into two locations on the Verde River and a single stocking of 2,046 fish were stocked in 1996 in the Salt River. Numerous fish were recaptured (283 in the Verde River and 2 in the Salt River) and survival up to six years was documented (Hyatt 2004). However, limited post stocking monitoring (once per year) did not allow for adequate assessment of survival. In addition, ripe males were encountered in the Verde River, but no evidence of reproduction or recruitment was found (Hyatt 2004). Because of a lack of recaptures, which indicates low adult survival despite stocking efforts, the Verde River will not be assessed in this report as a population.

In summary, razorback sucker adults are present and spawning across much of the Colorado River basin but some areas have patchy distributions. Species presence is likely due to the species' ability to utilize both lotic (rapidly moving fresh water like a river) and lentic (still, fresh water like a reservoir or lake) environments. Four populations, all maintained by stocking, are currently present in the UCRB, including in the Green, Colorado and San Juan subbasins and Lake Powell. LCRB populations currently occur in Lake Mead (and the Colorado River upstream of Lake Mead), Lake Mohave, the Colorado River between Davis and Parker dams (Lake Havasu), and the Colorado River below Parker dam, and all except the first are maintained by stocking. Although other, smaller, isolated, and more localized sources of razorback sucker can be found in various ponds, backwaters, and other habitat types common to the LCRB, they are not included herein as not all are sampled routinely or with the specific purpose to produce abundance estimates.

2.4 Life History

Razorback sucker is one of the better-studied species of Colorado River fishes, and its life history has been described by numerous researchers (Bestgen 1990; W. L. Minckley *et al.* 1991; U.S. Fish and Wildlife Service 1998; U.S. Fish and Wildlife Service 2002; Stymeist 2005; Valdez *et al.* 2011; Marsh *et al.* 2015).

Conceptual models are useful to diagram life stages and help elucidate biotic and abiotic factors that control life stages of a species (D. R. Smith *et al.* 2018). Razorback sucker life history can be divided into five life stages eggs, larvae, juveniles, adults and spawning adults. The basic needs of each life stage are described below and summarized at the end of this section (Table 1).

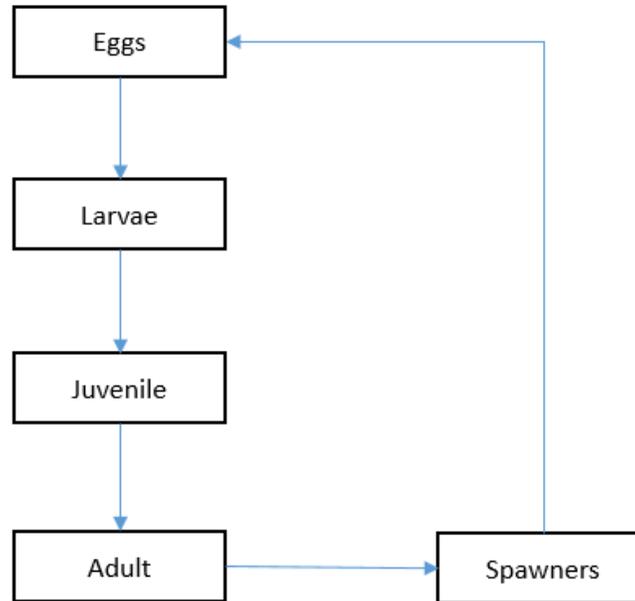


Figure 5. Simplified razorback sucker life stage model adapted from Valdez *et al.* 2011, which will be used to show relationships between species needs, risks and conservation actions through the SSA.

2.4.1 Feeding

Razorback sucker diet is dependent on life stage, habitat, and food availability. Razorback sucker larvae have terminal mouths and shortened gut lengths, which appear to facilitate and necessitate selection of a wide variety of food types. Transition from nourishment by the yolk to exogenous feeding by mouth occurs at approximately 10 mm TL (approximately 8–19 days post-hatch), after which larvae from lentic systems feed mainly on phytoplankton and small zooplankton, while lotic-inhabiting larvae are assumed to feed largely on chironomids and other benthic insects (W. L. Minckley and Gustafson 1982; Marsh and Langhorst 1988; Bestgen 1990; Papoulias and Minckley 1990; U.S. Fish and Wildlife Service 1998). In hatchery studies, larval razorback sucker survival is enhanced when food levels are within the range of 50–1,000 organisms/liter (Papoulias and Minckley 1990). As razorback sucker grow, they undergo an ontogenetic shift in mouth morphology, with the mouth becoming more inferior, allowing juveniles more efficient access to benthic food sources (U.S. Fish and Wildlife Service 1998).

As adults, razorback sucker display differing diet compositions, depending on whether the individual exists in a lotic or lentic setting (Bestgen 1990; U.S. Fish and Wildlife Service 1998). Lotic adult razorback sucker consume a mixture of benthic invertebrates, algae, detritus, and inorganic materials, but there is little evidence of zooplankton consumption in rivers (Jones and Sumner 1954; Banks 1964; Vanicek 1967). Lentic-inhabiting adult razorback sucker diets are dominated by cladoceran zooplankton; some algal and detrital materials are also present in gut contents (W. L. Minckley 1973; Marsh 1987).

2.4.2 Breeding

Razorback sucker take 2-6 years to reach maturity, depending on rearing habitat, which equates to 350 to 450 mm TL or greater (Bestgen 1990; Albrecht *et al.* 2009). Fecundity for razorback sucker, expressed in terms of number of ova per unit standard length (ova/SL) ranges from 1,600 ova/cm SL to 2,000 ova/cm SL (W. L. Minckley 1983). During the spawning season in LCRB reservoirs, male/female ratios of captured razorback sucker range from 1.2–3.6: 1 (Bozek *et al.* 1984; Albrecht *et al.* 2014) and were documented at 2.5:1 in the Green River (Bestgen 1990).

Razorback sucker's spawning season varies latitudinally, and thus between basins. In UCRB riverine habitats, ripe razorback sucker have been collected from mid-April to mid-June (4–5 weeks) when temperatures reach 14–16°C and springtime flows peak (Tyus 1987; D. B. Osmundson and Kaeding 1989a; D. B. Osmundson and Kaeding 1989b; Bestgen 1990; Tyus and Karp 1990a; Tyus and Karp 1990b). In lotic environments where higher spring flows connect backwater and floodplain habitats, adult razorback sucker have been documented moving into these areas that are typically 2–4°C warmer than main channel environments. This behavior is called “staging,” and it presumably allows additional thermal units to be obtained, which is thought to stimulate gamete production and minimize the costly act of spawning (Tyus and Karp 1990a; U.S. Fish and Wildlife Service 1998; Holden 1999; Ryden 2000). In the UCRB, spawning razorback sucker use substrate consisting largely of cobble, located in water velocities of approximately 1.0 m/s and depths of 1 m (McAda and Wydoski 1980). Spawning and egg deposition occurs in flooded lowlands and in eddies formed at river confluences or on main-channel gravel and cobble bars (McAda 1977; McAda and Wydoski 1980; Tyus 1987; Tyus and Karp 1990a; Modde and Irving 1998). Spawning in riverine sections has also been associated with increasing spring flows and associated turbidity (Tyus 1987; Tyus and Karp 1990a; Modde *et al.* 2005). Spawning razorback sucker have also been found in Lake Powell over talus (Francis *et al.* 2015).

In lentic LCRB habitats, the majority of spawning generally occurs between January and April when water temperatures are typically 10–20 °C or higher (Albrecht *et al.* 2008; BIO-WEST unpublished data). Spawning populations have been located in Lake Mead (Jones and Sumner 1954; Holden *et al.* 1997; Holden *et al.* 1999; Holden *et al.* 2000a; Holden *et al.* 2000b; Holden *et al.* 2001; Abate *et al.* 2002; Welker and Holden 2003; Albrecht, Sanderson *et al.* 2008; Albrecht, Holden *et al.* 2010; Albrecht *et al.* 2013a; Kegerries *et al.* 2015; Mohn *et al.* 2015), Lake Mohave (Bozek *et al.* 1984; Marsh and Langhorst 1988; Mueller 1989; Bozek *et al.* 1990; Marsh *et al.* 2015), Lake Havasu (P. A. Douglas 1952; W. L. Minckley 1983; R. Wydoski and Mueller 2006) and Senator Wash Reservoir (Medel-Ulmer 1980; Kretschmann and Leslie 2006). Spawning activities are most frequently associated with relatively shallow, flat to gently sloping shoreline areas over relatively clean gravel and cobble (Bestgen 1990). Spawning activity has been documented in depths of up to 20 m in Lake Mead, but it typically occurs in less than 2 m of water (W. L. Minckley *et al.* 1991; Holden *et al.* 1997; Holden *et al.* 1999). Spawning fish often congregate near river inflow areas, which are usually more turbid than most available habitats (Jones and Sumner 1954; Holden *et al.* 1997; Holden *et al.* 1999; Albrecht *et al.* 2010; Albrecht *et al.* 2014; Kegerries *et al.* 2015).

Razorback sucker display strong spawning site fidelity, both in lentic and lotic habitats (Mueller 1989; Tyus 1990; Holden *et al.* 2000a; Holden *et al.* 2000b; Holden *et al.* 2001; Abate *et al.* 2002; Welker and Holden 2003; Welker and Holden 2004; Modde *et al.* 2005).

2.4.3 *Survival and Growth*

Successful razorback sucker egg incubation occurs above 8°C, primarily from 9.5 to 20°C (W. L. Minckley and Gustafson 1982; Bozek *et al.* 1990). Egg mortality has been attributed to fluctuating water levels, current scouring and/or wave action, suffocation due to silt deposition, and nonnative predation (W. L. Minckley 1983; Bozek *et al.* 1984). Additionally, dissolved oxygen concentrations below 2.5 milligrams per liter (mg/L) and high salinity (11,000–12,000 microsiemens per liter [$\mu\text{S/L}$]) are fatal to egg incubation (Stolberg 2012a; Stolberg 2012b). In laboratory experiments, the majority of larval mortality likely occurs within 20–30 days of hatching and is a result of starvation, indicating that zooplankton levels are an important driver of larval razorback sucker survival (Papoulias and Minckley 1990).

Published growth estimates for razorback sucker vary and available information is highly dependent on life stage, habitat type, and overall ecological setting (e.g., temperature, food availability; see reviews by Bestgen 1990 and U.S. Fish and Wildlife Service 1998). Most growth information for larval and juvenile razorback sucker has been based on hatchery-produced fish (Marsh 1985; Brooks 1986; Marsh and Brooks 1989; W. L. Minckley *et al.* 1991; Mueller 1995). Razorback sucker that are 7–9 mm at hatch can reach lengths of more than 23 mm TL within 2 months (Papoulias and Minckley 1990). Fish growth is dependent on both water temperature and the quality and quantity of food available; water temperatures above 25 C dramatically decreased the time required to reach 25 mm, which is thought to be a threshold to reduce predation (Bestgen 2008). Subsequently, during the initial 6 years of life, razorback sucker appear to grow rapidly (e.g., growth of 55–307 mm TL in 6 months for young razorback sucker stocked into ponds) (D. B. Osmundson and Kaeding 1989a), after which growth is minimal (2.0 mm TL/year or less) (McCarthy and Minckley 1987; W. L. Minckley *et al.* 1991; Modde *et al.* 1996).

Snyder *et al.* (2004) describe the transition from larvae to juvenile as beginning at 27–30 mm TL and ending at 32–35 mm TL. The juvenile razorback sucker life stage ranges from 27–450 mm TL depending on capture location and fish origin. Generally, fish in the UCRB greater than 350 mm TL are sexually mature (Muth *et al.* 2000).

2.4.4 *Dispersal*

Dispersal of razorback sucker larvae from spawning bars in rivers occurs during high spring runoff flows. These small, drifting larvae are more likely to survive if they drift into floodplain wetlands, which are food-rich and protected from predators (Muth *et al.* 2000). Success can depend on the magnitude and duration of spring discharge, proximity to and interaction with floodplains, water temperature and variability, geomorphic factors, and turbidity. The relationship between river flow and floodplain connection is important to drifting larvae; it ensures that larvae become entrained in food-rich habitats (Bestgen *et al.* 2011; LaGory *et al.* 2012). Movement of juveniles has been studied in reservoirs, finding movements of up to 7 km

per day (Mueller and Marsh 1998). Dispersal movements are also common until adequate habitat is found, which varies between shallower habitats with cover during most of the year and retreat to deeper waters during warm summers (Kegerries, Shattuck *et al.* 2015; Kegerries, Albrecht, Mohn *et al.* 2017).

Provided there are no artificial barriers, adult razorback sucker can move long distances throughout the river systems including between subbasins, though most do not (STReaMS 2016). Three fish stocked into the San Juan River in 2004 and 2006 were captured in 2008 near the Colorado-Utah state line on the Colorado River, each having moved over 550 km. Another razorback sucker stocked into the San Juan River in 2010 was captured in the Green River in 2011 at river-km 159, also traveling more than 550 km (Durst and Francis 2016). These movements may be related to spawning, but do indicate that long-distance movements are possible.

2.4.5 *Habitat*

It appears that razorback sucker use available habitat, regardless of location. Historically, razorback sucker inhabited virtually all components of low velocity riverine habitat; backwaters, floodplains, sloughs, oxbow lakes, and other slackwater habitats within the main channel were particularly important (Holden 1973; Holden and Stalnaker 1975; Behnke and Benson 1983; W. L. Minckley 1983). Reaches in the UCRB tend to consist of higher-gradient, erosional, dynamic sections, whereas LCRB riverine habitats are more depositional, channelized, homogenous habitat types occasionally interspersed with highly vegetated, perennial, and permanently connected man-made off-channel backwater and floodplain impoundment structures (Bradford and Gurtin 2000). Seasonally submerged off-river habitats including bottomlands and other marsh-like, lowland habitats likely were important habitat for razorback sucker prior to the construction of mainstream dams (Tyus and Karp 1989; Bestgen 1990; D. B. Osmundson 2001). The razorback sucker is also known to complete its entire life cycle within lentic habitat types (Albrecht *et al.* 2010) and likely did so historically within the off-channel, backwater, and floodplain habitats described above. This information lends additional insight into the overall plasticity of razorback sucker, assuming certain levels of habitat complexity, cover, and predation/competition levels are available (Albrecht *et al.* 2010).

In lotic settings, larval razorback sucker are often associated with backwater and in-channel slackwater-type habitats with low velocities (Tyus 1987; Muth *et al.* 1998). However, construction of mainstem dams, coupled with channelization and detrimental competition from and predatory effects of nonnative fishes, has likely contributed to elimination of important nursery areas. Many nursery habitats have been cut off or presently serve as strongholds for nonnative fishes that prey on and compete with young razorback sucker (Tyus and Karp 1990a; D. B. Osmundson and Kaeding 1991; W. L. Minckley *et al.* 1991; Mueller 1995; Tyus and Saunders 1996; Modde *et al.* 2005).

Habitat preferences for juvenile razorback sucker remain relatively understudied, as captures of this size class have been minimal in recent years (Tyus 1987; Bestgen 1990; U.S. Fish and Wildlife Service 1998; Albrecht *et al.* 2009; Shattuck *et al.* 2011). Historical data indicate large assemblages of juveniles in river margins warmer than the river itself (Sigler and Miller 1963).

Telemetry data demonstrated that juvenile razorback sucker utilized backwaters, vegetated areas, and rocky cavities thought to provide important cover and food resources (Mueller and Marsh 1998). Additionally, warmer (18–26.6°C) backwater-type habitats presumably allow for rapid growth during this life stage (Modde *et al.* 2001; Snyder *et al.* 2004). This description of habitat use is corroborated by the recapture of two experimentally stocked juvenile razorback sucker in the San Juan River (Holden 1999). These fish occupied slackwater and backwater pools that were 0.3–0.9 m deep and 1–3°C warmer than adjacent main-channel habitats. Juvenile razorback sucker also inhabit floodplain depressions (depth = 1.0–2.0 m, dissolved oxygen greater than 2.0 mg/L [usually above 5.0 mg/L], and maximum surface temperatures of 26.6 °C) because of habitat variables such as zooplankton density, water temperature, depth, and vegetative cover abundance (Modde 1996; Modde 1997; Modde *et al.* 2001; Modde and Haines 2005). Growth and survival are greater in floodplain depressions than main-channel habitats, and can provide a refuge from nonnative predation when actively managed (Schelly and Breen 2015).

Lake Mead razorback sucker studies document the capture of wild juvenile (sexually immature) razorback sucker, mainly collected along shallow shoreline habitats, near turbid inflow areas, and proximal to submerged vegetation, suggesting that densely covered, complex habitat types may provide an escape from nonnative predation (Holden *et al.* 1997; Holden *et al.* 1999; Holden *et al.* 2000a; Holden *et al.* 2000b; Holden *et al.* 2001; Abate *et al.* 2002; Welker and Holden 2003; Welker and Holden 2004). Telemetry efforts depict the generally cryptic nature of this life stage as evidenced by minuscule movement patterns, heavy utilization of cover types (including both vegetation and turbidity), possible nocturnal movement patterns during some seasons, and an affinity for marginal habitats that were relatively devoid of nonnative fishes within complex Lake Mead inflow habitats (Albrecht *et al.* 2013b; Shattuck and Albrecht 2014; Kegerries *et al.* 2015; Kegerries *et al.* 2017).

In lotic systems, adult razorback sucker use pools and slow eddies from November through April (Ryden 2000). As flows rise in the spring, razorback sucker associate with eddies along the inside of large river bends; displaying a strong affinity for mid-channel cobble riffles and run/riffles, as well as shoreline cobble-shoal-run type habitats (Ryden 2000). Adult fish increased their use of backwater habitats during May and June (D. B. Osmundson and Kaeding 1989a) and shift to higher velocity waters associated with submerged mid-channel sandbars in the summer (Tyus 1987; Ryden 2000). Few adult razorback sucker utilize swift, whitewater habitats (like Blackrocks and Westwater canyons in the UCRB), although movement of fish through these locations has been documented (Tyus and Karp 1990a; Albrecht *et al.* 2014; Kegerries *et al.* 2015).

In lentic systems, studies adult razorback sucker use a wide variety of habitats, including inundated vegetation, shorelines, and substrates ranging from silt and sand to gravel and cobble (Albrecht *et al.* 2008a). Adult razorback sucker occupy depths less than 30 m, generally located within 100 m of the shore during the winter, and less than 30 m from shore during peak spawning; however, during the summer, adults were located at depths often surpassing 30 m, (Marsh and Minckley 1989; Holden *et al.* 1997; Holden *et al.* 1999; Mueller *et al.* 2000; Holden *et al.* 2000a; Holden *et al.* 2000b; Holden *et al.* 2001; Abate *et al.* 2002; Welker and Holden 2003; Welker and Holden 2004; Albrecht, Kegerries *et al.* 2008; Albrecht *et al.* 2010; Albrecht *et al.* 2014; Kegerries *et al.* 2015). Adult razorback sucker are found in reservoir inflow areas

where the presence of turbidity may be important for all life stages of razorback sucker to avoid predation from nonnative species (Albrecht *et al.* 2017). Turbidities greater than 500 NTU may reduce sight feeder predation on juvenile razorback sucker by 50% (B. Vaage, D. Ward, and R. Morton-Starner, U.S. Geological Survey, unpublished data). Typically, inflow areas will show higher turbidity than reservoir basins year-round. Substrate complexity that can be used for spawning and feeding is often found within these inflow areas. Furthermore, large wood and vegetation transported from the river channel provides unique, much needed structure at each of these zones (Albrecht *et al.* 2017).

Table 1. Selected information describing observed conditions for razorback sucker by life stage and references.

Life Stage	Resource Information	References
Fertilized Eggs	Clean rocky substrates for adhesive eggs for 3–4 hours post fertilization. Gravel and cobble, at near shore locations, and typically at depths of <4.9 m, but have been noted to spawn over clay/dirt beds	Sigler and Miller 1963; Minckley and Gustafson 1982, Minckley 1983; Bozek <i>et al.</i> 1984; Marsh and Langhorst 1988; Holden <i>et al.</i> 1997, 1999, 2000a, 2000b, 2001; Abate <i>et al.</i> 2002; Welker and Holden 2003, 2004; Albrecht <i>et al.</i> 2008, 2010, 2014; Kegerries <i>et al.</i> 2015a
	Survive in water temperature 9.5–20 °C, at 15.0° C eggs hatch in 5.2–11.4 days	Minckley and Gustafson 1982, Bozek <i>et al.</i> 1984
	Successful hatch reduced <= 10°C	Bozek <i>et al.</i> 1984
	Dissolved oxygen >2.5 mg/L	Stolberg 2012a
	Salinities between 1,000–3,000 µS/cm were most successful but can tolerate upwards of 12,000 µS/cm. Eggs display greater sensitivity to salinity than larvae	Stolberg 2012b
Larvae (9–27 mm TL)	Diet rich with invertebrates increases growth, 50–1,000 invertebrates/L for minimal mortality	Snyder <i>et al.</i> 2004; Papoulias and Minckley 1992; Papoulias and Minckley 1990
	Lotic - Backwater, floodplain, and in-channel slackwater habitats and flows sufficient to move larvae into these habitats.	Tyus 1987; Muth <i>et al.</i> 1998; Bestgen <i>et al.</i> 2011
	Lotic - Chironomids and other benthic insects	Minckley and Gustafson 1982; Marsh and Langhorst 1988
	Lentic - Phytoplankton and small zooplankton	Minckley and Gustafson 1982; Marsh and Langhorst 1988; Papoulias and Minckley 1990
	10–26.6 °C with 18–20 °C being typical	Modde <i>et al.</i> 2001; Snyder <i>et al.</i> 2004
	Dissolved oxygen >2.5 mg/L	Stolberg 2012a
	Can survive in salinities as high as 23,000–27,750 µS/cm	Stolberg 2012b

2 Species Overview

<p>Juvenile 27 to <450 mm TL and sexually immature</p>	<p>Benthic-associated food items</p>	<p>U.S. Fish and Wildlife Service 1998; Snyder <i>et al.</i> 2004; Albrecht <i>et al.</i> 2009; Shattuck <i>et al.</i> 2011</p>	
	<p>Lotic</p>	<p>Backwaters, floodplains , vegetated areas, rocky substrates, and flows sufficient to maintain healthy conditions</p>	<p>Mueller and Marsh 1998; Mueller 2006; Bestgen <i>et al.</i> 2011</p>
	<p>Dissolved oxygen >2.0 mg/L, usually > 5.0 mg/L, and maximum temperatures 26.6 °C</p>	<p>Modde 1996 and Modde <i>et al.</i> 2001</p>	
	<p>Lentic</p>	<p>22.9–26.6 °C</p>	<p>Bulkley and Pimentel 1983; Modde 1996; Modde <i>et al.</i> 2001</p>
	<p>Shallow shoreline habitats, near turbid inflow areas and submerged vegetation</p>	<p>Holden <i>et al.</i> 1997, 1999, 2000a, 2000b, 2001; Abate <i>et al.</i> 2002; Welker and Holden 2003, 2004</p>	
<p>Cover types including vegetation and turbidity, possible nocturnal movement patterns during some seasons, and the affinity to utilize marginal habitats that are mostly devoid of nonnative fishes within inflow habitats</p>	<p>Albrecht <i>et al.</i> 2013; Shattuck <i>et al.</i> 2014; Kegerries <i>et al.</i> 2015a</p>		
<p>Adult (sexually mature)</p>	<p>Lotic</p>	<p>Mixture of benthic invertebrates, algae, detritus, and inorganic materials</p>	<p>Banks 1964; Vanicek 1967</p>
	<p>Lentic</p>	<p>Midge (chironomid) larvae, cladoceran zooplankton, with some degree of algal and detrital material</p>	<p>Jonez and Sumner 1954; Minckley 1973; Marsh 1987</p>
	<p>Lotic</p>	<p>Inhabited virtually all components of riverine habitat, including low-velocity habitats such as backwaters, floodplains, sloughs, oxbow lakes, and other slackwater habitats within the main channel</p>	<p>Holden 1973; Holden and Stalnaker 1975; Behnke and Benson 1980; Minckley 1983; Mueller 2006</p>
	<p>Winter</p>	<p>Pools and slow eddies from November through April</p>	<p>Osmundson and Kaeding 1989a</p>
<p>Notably sedentary main channel runs, eddies, and shore runs that averaged 1.1 m deep with velocities of 0.3 m/s were selected habitats</p>	<p>Ryden 2000</p>		

During prerunoff periods (March and April), fish used a variety of low-velocity habitats, such as slackwaters, pools, sand-shoals, flooded near-shore areas and submerged, off-river habitats including bottomlands and other marsh-like, lowland habitats.

Ryden 2000; Tyus and Karp 1990; Tyus 1987; Tyus and Karp 1989; Osmundson 2001; Bestgen 1990

Summer

Subsequently shifted habitat use to shallow waters associated with submerged mid-channel sandbars

Tyus 1987

Backwater habitat use May and June

Osmundson and Kaeding 1989a

Shifting to runs and pools from July through October

Osmundson and Kaeding 1989a

Inundated vegetation

Ryden 2000

Mean depth was 1.2 m, velocity 0.7 m/s and mean temperature=21.1 °C

Ryden 2000

Autumn

Shift from slow to fast main channel habitats with depths of 1.2–1.9 m, temperature=5.3 °C and velocity= 0.4 m/s

Ryden 2000

Lentic

Wide variety of habitats: pelagic, vegetated areas, littoral shoreline

Minckley *et al.* 1991; Albrecht *et al.* 2008; Marsh *et al.* 2015, and numerous others

Substrates: silt and sand, to gravel and cobble

Minckley *et al.* 1991; Albrecht *et al.* 2008; Marsh *et al.* 2015, and numerous others

<30 m deep (averaging between 3.1–16.8 m), within 100 m from the shore during winter months (less than 30 m from shore during peak spawning activity)

Marsh and Minckley 1989; Holden *et al.* 1997, 1999, 2000a, 2000b, 2001; Mueller *et al.* 2000; Abate *et al.* 2002; Welker and Holden 2003, 2004; Albrecht *et al.* 2008; Albrecht *et al.* 2010a; Albrecht *et al.* 2014; Kegerries *et al.* 2015a

Summer months, adults were located at deeper depths, often > 30 m

Thermal preference lies within the range of 22–25 °C based on laboratory observations and lethal temperature of 30–41 °C

Bulkley and Pimentel 1983

2 Species Overview

Spawners	<i>Lotic</i>	
	Spawning associated with the ascending limb of hydrograph	Ryden 2000
	Cobble-bottomed riffles or substrates consisting of scoured sands and gravels. Mean depths of 1-2 m with velocity of 0-0.4 m/s and mean temperature of 14.8 °C	Ryden 2000, Mueller 1989
	<i>Lentic</i>	
	10 °C to more than 20 °C	Bestgen 1990; Albrecht <i>et al.</i> 2008; unpublished BIO-WEST data
2–20 m deep	Holden <i>et al.</i> 1997, 1999; Minckley <i>et al.</i> 1991	
Primarily clean, gravel- and cobble-sized substrates, but other substrate types have been documented	Douglas 1952; Bozek <i>et al.</i> 1990; Minckley <i>et al.</i> 1991; Tyus 1987; Tyus and Karp 1990	
Near river inflow areas with more turbid areas and stands of inundated vegetation	; Holden <i>et al.</i> 1997, 1999; Albrecht <i>et al.</i> 2010a; Albrecht <i>et al.</i> 2014; Kegerries <i>et al.</i> 2015a	

3 SPECIES NEEDS

Some needs of razorback sucker are specific to a single life stage, while others apply to multiple life stages, populations or the species as a whole. These needs, which are described in more detail in the section above (Table 1, above), can be summarized as eight fundamental categories. We note that not all needs are limiting factors for each respective level, and although they may be present in the abiotic environment, access to these required needs may be restricted due to stressors and risks summarized in Chapter 4 of this document. For example, the impacts of aquatic nonnative species that compete with, or prey on, razorback sucker may interact with each of these parameters and therefore limit access to the resources even if they are present. Species needs describe our current understanding of the species. More information may lead to alternative conclusions as scientific studies become more robust or more is known about historic conditions.

3.1 Complex lotic and/or lentic habitat (*Individual need*)

Depending on life stage and location, the razorback sucker uses the suite of available habitats in reservoirs, main channels, backwaters, and floodplain wetlands. Three specific habitat types are thought to be necessary to complete the life cycle. First, razorback sucker use rocky substrates of boulder, cobble, and clean gravel usually along river margins, mid-channel bars, and island complexes, or reservoir, floodplain, and backwater shorelines for spawning adults and subsequent egg development. Second, larvae and juveniles need access to persistent, shallow, and warm, sheltered shorelines of backwaters, floodplains, or similar habitat types with cover present (vegetation and/or turbidity) to avoid predation. Inflow areas provide some of the best spawning and juvenile habitat similar to historic backwaters, floodplain wetlands, and other features. High cover in the form of turbidity and/or emergent or submerged vegetation likely provides protection from predation and allows for greater survival of small fish (R. S. Wydoski and Wick 1998; Mueller 2006; Albrecht *et al.* 2014; Kegerries *et al.* 2015). Third, adults need pockets of deeper water, either in reservoirs, large eddies or pools with slow velocities.

3.2 Suitable water temperature and quality (*Individual need*)

The razorback sucker is a warm water adapted species. Temperature preference of adult razorback sucker was estimated at 22–25 °C, based on laboratory observations (Bulkley and Pimentel 1983). This species was historically known for its migrations to spawning locations, and today this same attribute likely benefits the species by allowing adults to find appropriate thermal regimes, whether in the lotic, lentic or some combination of the two environments (W. L. Minckley *et al.* 1991; Valdez *et al.* 2011; Valdez *et al.* 2011). Larvae have been captured in water ranging from 10.0 to 26.6 °C, but they are more frequently collected in 18.0–20.0 °C water (Marsh 1987; Modde *et al.* 2001; Modde *et al.* 2001; Snyder *et al.* 2004; Snyder *et al.* 2004). Razorback sucker are tolerant of a wide range of water quality conditions, including pH ranges between 6.0 and 9.0 (Slaughter *et al.* 2002), dissolved oxygen levels as low as 2.0 mg/L (Modde 1996; Modde *et al.* 2001; Modde *et al.* 2001; Stolberg 2012a; Stolberg 2012a) and salinities of up to 23,000–27,750 µS/cm (Stolberg 2012b). While razorback sucker are adapted to a variety of water quality conditions, the need for water quality conditions within these ranges remains.

Tolerance levels to other water quality contaminants remain unknown, including the effects of metals or endocrine disrupting chemicals.

3.3 Variable Flow Regimes (*Individual need*)

Specific flow regimes have not been well identified for razorback sucker, but adults are often found in riverine habitats where the current velocity is near 0.5 m/sec (Ryden 2000). More than likely, the species benefits from variable flows mimicking natural pre-dam conditions that maintain channel diversity, stimulate food production, and disadvantage nonnative predators and competitors (Muth *et al.* 2000). As evidenced in the UCRB, in lotic settings, the species spawns on the ascending limb of spring runoff, and typically spawns on rocky shorelines and mid-channel cobble-gravel bars that are generally available over a range of flows (Muth *et al.* 2000). Flows sufficient to entrain larval razorback sucker into backwaters, floodplain wetlands, and other similar habitat types are considered essential for this species in these environments (Bestgen *et al.* 2011; LaGory *et al.* 2012). Inter-annual variability in peak flows drives connections to many of these floodplain environments. In lentic settings, reservoir elevation patterns have been considered important for reproduction, egg, and larval survival (W. L. Minckley *et al.* 1991; Albrecht *et al.* 2010). In these lentic systems, the presence of sufficient flow/water availability is more essential than the variation in that flow. Variable flow regimes are applicable only to lotic populations.

3.4 Food supply (*Individual need*)

Sufficient food is required to maintain growth and health of razorback sucker. The razorback sucker has an omnivorous diet that appears to shift by life stage. Diet composition is highly dependent on habitat and food availability. Larval razorback sucker survival is maximized when food levels are within the range of 50–1,000 organisms/liter (Papoulias and Minckley 1990). During later growth, razorback sucker undergo an ontogenetic shift in mouth morphology, thereafter, razorback sucker, while continuing to be opportunistic feeders, likely consume a variety of food items (U.S. Fish and Wildlife Service 1998).

3.5 Range and Connectivity (*Species need*)

Range and connectivity are important to razorback sucker, as the species was historically migratory, particularly during spawning (W. L. Minckley *et al.* 1991). The ability to move within and among systems supports populations through access to appropriate habitat and genetic exchange. Migrations of this species can be limited by large dams or unmodified diversions, and the presence of large-bodied nonnative predators but the species has nevertheless been observed navigating hundreds of miles within both reservoir and riverine environments (Durst and Francis 2016).

3.6 Population size and numbers (*Population need - Resiliency*)

Resilient populations have demographic ability to absorb and bounce back from disturbance and persist at the population or meta-population scale (D. R. Smith *et al.* 2018). To do that, abundance of individuals must be sufficient to maintain a healthy population and the organism

must be able to complete all life stages to ensure biological succession. Razorback sucker have shown the ability to develop large populations, which have previously been recorded at levels greater than 100,000 adults (Marsh *et al.* 2015). Abundance is typically measured as the number of adults per population present in the system. Additional indications of population resiliency are the documentation of varying life stages, including spawning and larval presence, presence of juveniles, the documentation of naturally recruited adults, and self-sustaining populations able to provide population stability.

3.7 Multiple, interconnected, naturally recruiting, and resilient populations (*Species need - Redundancy*)

Redundancy describes the ability of a species to withstand catastrophic events by spreading the risk among populations and is characterized by having multiple, resilient populations distributed across the range of the species (D. R. Smith *et al.* 2018). Redundant populations for razorback sucker exhibit use of multiple areas within a population range because all the populations defined in the SSA are geographically large (e.g. multiple bays in a reservoir, multiple rivers in a basin). Redundant populations in lotic systems occupy habitats across a geographic extent including the use of the mainstem and multiple tributaries. In lentic systems, few barriers exist across the reservoir other than the presence of nonnative fish, and razorback sucker are often present at multiple locations (e.g., tributary mouths) that could allow for recolonization in the event of catastrophe. Multiple, self-sustaining, proximal populations in different watersheds without major barriers between them (e.g., Green, Colorado rivers) is a favorable distribution arrangement for the species to allow transition of individuals among populations for genetic exchange and demographic rescue.

3.8 Genetic and ecological diversity (*Species need - Representation*)

Maintaining representation in the form of genetic and ecological diversity is important to maintain the capacity of the razorback sucker to adapt to future environmental changes. Genetic analysis of the species indicates that, although the different populations display slightly different genetic characteristics and levels of diversity, historical diversity (Dowling *et al.* 2012) appears to be well maintained. It is important to note that genetic data for this species is from the 1980's and 1990's, a period when populations of razorback sucker already were declining (Tom Dowling, Wayne State University, personal communication). The species demonstrates an ability to inhabit to lake and inflow environments and to persist where river habitats have been altered which points to important ecological diversity.

3.9 Summary of Species Needs

Overall, razorback sucker individuals need certain habitat characteristics including complex lotic or lentic habitat for spawning, juvenile rearing habitat, and adult habitat, suitable water temperature and quality, variable flow regimes (for lotic systems), and an adequate food supply. The habitat characteristics affect varying life stages of the species, which collectively define a population's resilience (Figure 6). The species needs multiple, resilient populations (*Redundancy*) and maintenance of genetic and ecological integrity (*Representation*).

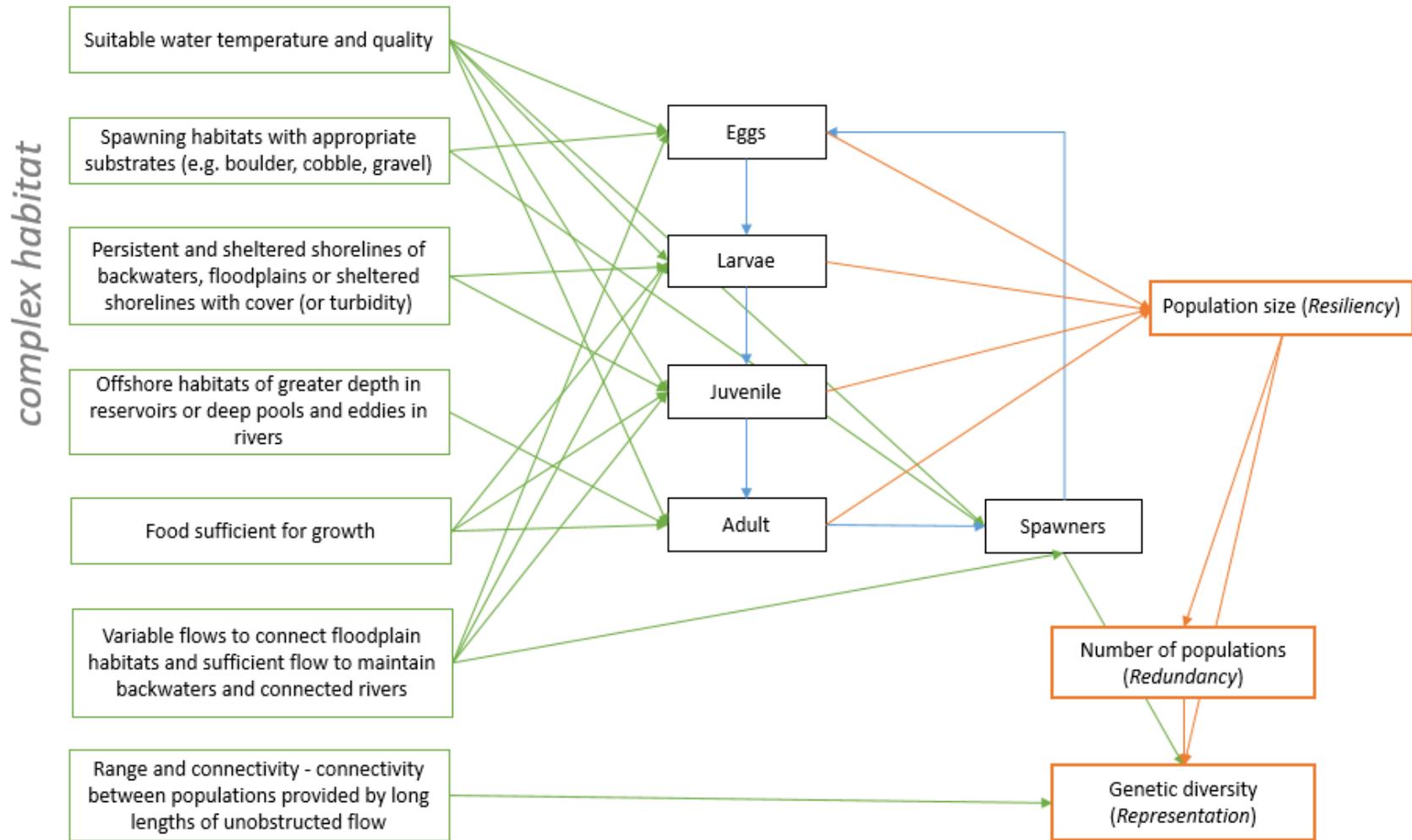


Figure 6. Flowchart of individual and population level needs (green) and the life stages they affect (black) in relation to species level needs of resiliency, redundancy, and representation (orange).

4 RISK AND CONSERVATION FACTORS

In this chapter, we evaluate the past, current, and future influences affecting razorback sucker current and future viability. Risks (or stressors) and conservation actions are explored to help explain both current and future condition of the razorback sucker across the eight populations in the upper and lower basins. The risks to razorback sucker include climate change, genetic factors (hybridization, inbreeding, reduced population size), habitat (flow regime/connectivity, land use, water management/habitat availability, and water temperature), nonnative and invasive species (competition, habitat effects, and predation), overutilization (use of species for various purposes), parasites and diseases, and pollutants (Figure 7). Conservation actions include augmentation, nonnative species management, program management and funding, research and monitoring, and water management / habitat availability (Figure 7). After risks and conservation actions were identified, an expert elicitation process (Delphi Process, Appendix A) was used to rank the factors most influential to razorback sucker over the next 30 years.

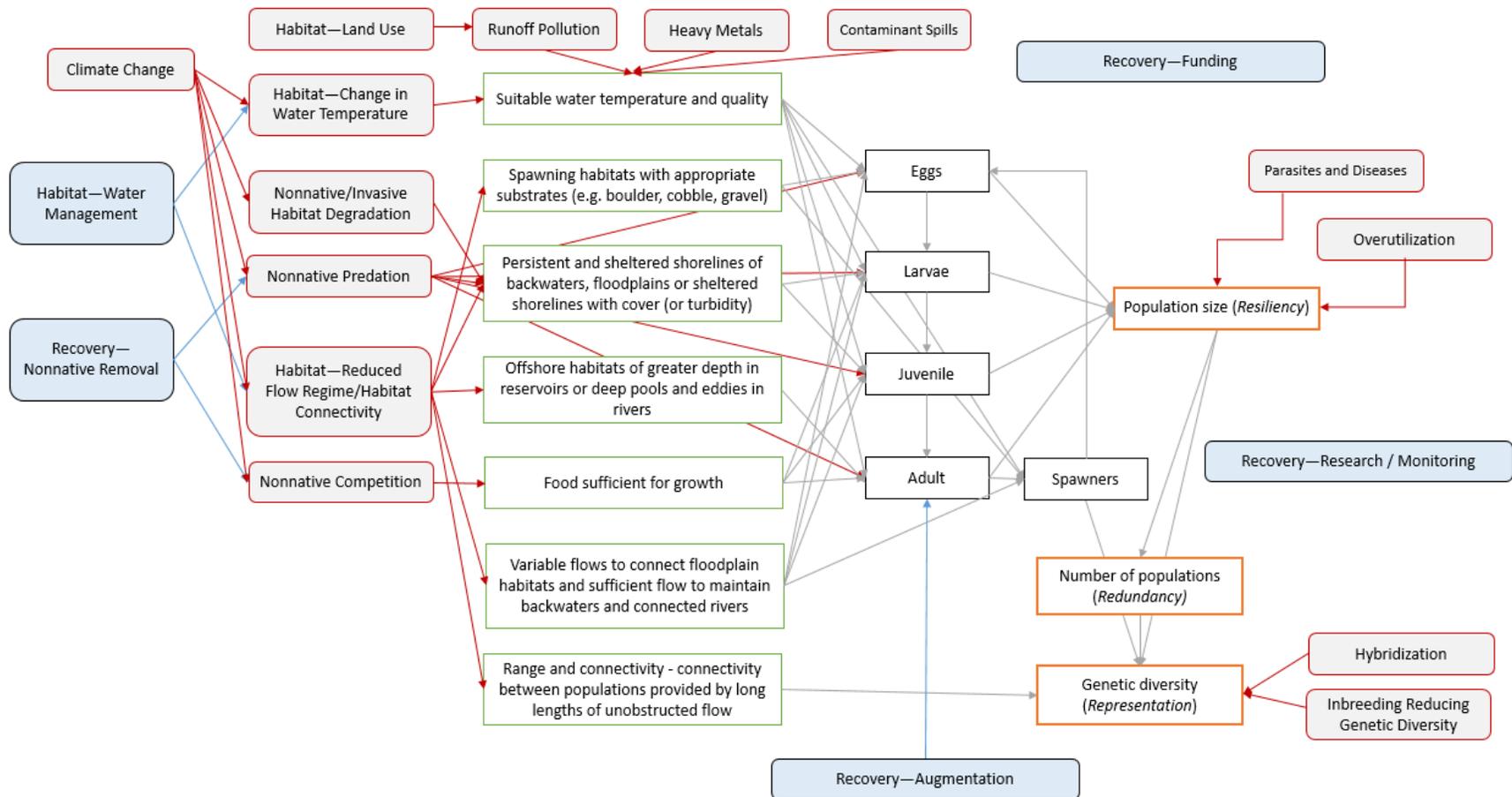


Figure 7. Flowchart of risks (gray with red outline) and management actions (blue rectangle) on razorback sucker individual and population needs (green outline) and their subsequent effects on the life stages (black outline) and 3Rs (orange outline). No lines are present connecting recovery program funding and research/monitoring to specific rectangles as they have overarching effects on the entire system.

4.1 Risks

4.1.1 Climate Change

Studies using predictive models indicate that changes in precipitation patterns, mean annual air temperature, and antecedent soil moisture will result in changes in flow patterns and magnitude in the Colorado River basin. Certain hydroclimate projections through 2099 (U.S. Bureau of Reclamation 2016b) indicate a slight increase in annual precipitation combined with an increase in mean annual temperature (Figure 8), while others project decreases in precipitation (nearly 6%) and associated snowpack (up to 76%) (Christensen *et al.* 2004), and resultant water supplies (Woodhouse *et al.* 2016). Even with a slight increase in annual precipitation, the risk of drought remains with continued temperature increases in the American Southwest (Christensen *et al.* 2004; Woodhouse *et al.* 2016; Ault *et al.* 2016). For example, an increase in mean annual air temperature of 2.4°C relative to historical climate in the Colorado River basin could decrease runoff by as much as 17% by 2098 (Nash and Gleick 1991; Christensen *et al.* 2004). (Nash and Gleick 1991; Christensen *et al.* 2004) Different combinations of changes in precipitation, temperature, and soil moisture can cause flow reductions of similar scales (Woodhouse *et al.* 2016); changes in climatic patterns can also result in earlier snowmelt and spring runoff, leaving summer base flows lower and warmer than they have been historically (Dennis 1991; Gleick and Chalecki 1999). The effects of a warming environment are already evident: between 2000 and 2014, Colorado River annual flows averaged 19.3% below the 1906-1999 period, one third of which was attributed to increased temperature alone (Udall and Overpeck 2017). Future conditions for razorback sucker could therefore include increased stream temperatures through reduced flows and increased air temperatures under drought conditions (Christensen *et al.* 2004; U.S. Bureau of Reclamation 2012; U.S. Bureau of Reclamation 2016b; U.S. Fish and Wildlife Service 2017).

The United States has experienced increased mean air temperatures of approximately 1.3 to 1.9°C since record keeping began in 1895, with most of the warming occurring since 1970 (U.S. Bureau of Reclamation 2016a). Continued warming throughout the 21st century is estimated to be 2.7 to 3.9°C (U.S. Bureau of Reclamation 2016a). As reported by the U. S. Fish and Wildlife Service (2017) and according to the Western Climate Mapping Initiative, during the 20th century mean air temperature increased approximately 1.2°C in the UCRB and approximately 1.7°C in LCRB. River water temperatures have also increased over the past decades. For example, from 1950 to 2015, mean annual water temperatures increased by about 13% in the Colorado River near Cisco, Utah and 11% in the Green River at Green River, Utah (U.S. Fish and Wildlife Service 2017). This was interpreted as decadal warming of about 1.5 °C in mean annual water temperatures in the Colorado River and 1.3 °C in the Green River (U.S. Fish and Wildlife Service 2017).

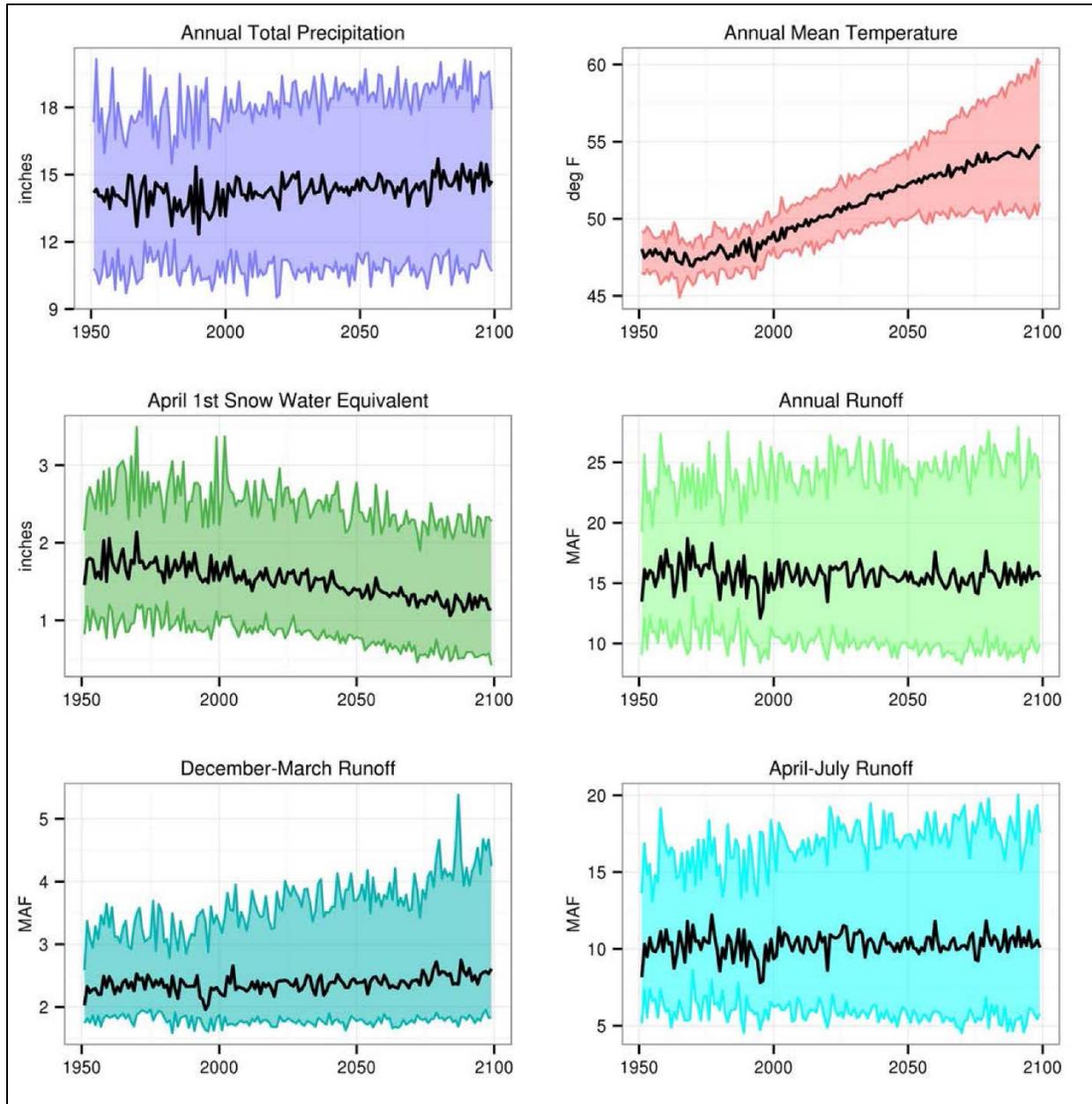


Figure 8. Time series plots for six projected hydroclimate indicators in the Colorado River basin from 1950-2099 (indicators title above each individual plot). The black line shows the annual time-series median value with the 10th and 90th percentiles shaded (Figure 1 from U.S. Bureau of Reclamation [Reclamation] 2016b).

In addition to altered stream temperatures, climate change could impact runoff conditions and annual hydrograph patterns, such as reduced April 1 snow water equivalent (Figure 8, middle left plot) and increased December to March runoff (Figure 8, bottom left plot). Altered hydrographs, especially decreased streamflow or earlier runoff would affect razorback sucker habitat, individuals, and populations. For example, decreased water quantity would decrease resource availability to individuals, increase competition with other fishes, and likely decrease water quality. In the upper basin, reduced runoff would reduce habitat-creating flows and earlier runoff could limit access to floodplain nursery habitats if peak flows occurred prior to larval razorback

sucker emergence (Bestgen *et al.* 2011; LaGory *et al.* 2012). Habitat changes could affect reproduction through decreased spawning habitat and reduction in survival and recruitment through increased predation and decreasing cover. In the lower basin, conditions in the Grand Canyon could become more suitable for razorback sucker as lower water levels in Lake Powell may increase temperatures and therefore increase habitat availability in the cool water stretches downstream of Glen Canyon Dam. However, increased introduction and expansion of warm-water nonnative fishes is also a risk under warming conditions in the Grand Canyon (Kegerries *et al.* 2015; U.S. Fish and Wildlife Service 2017).

Warming water temperatures, in conjunction with reduced stream flow, may also lead to increased growth rates and more rapid development of razorback sucker in some settings. However, warming water temperatures could also benefit survival, reproduction, and distribution of nonnative, warm-water species that are known to have negative impacts on razorback sucker survival and recruitment, such as smallmouth bass *Micropterus dolomieu* in the upper basin. Warm-water nonnative fish populations may further expand into areas currently occupied by razorback sucker. Although changes are expected to occur slowly over decades, the impact may be exacerbated if native fish temperature thresholds are exceeded while nonnative fishes are able to successfully reproduce and recruit in areas not currently occupied by nonnatives.

Razorback sucker's ability to spawn and recruit in both lentic and lotic habitats and reproduce at varying water temperatures suggests some tolerance and plasticity to climatic changes. For example, if stream conditions degrade, individuals may move to reservoir habitats, increasing the importance of reservoir inflow habitats to razorback sucker.

Overall, direct negative impacts from climate change primarily result from reduced runoff amounts or earlier peak flows, while indirect negative impacts are associated with increased production of nonnative fishes. Direct positive impacts from climate change includes warming of certain river reaches cooled by reservoir releases and potential increased growth rates.

4.1.2 Genetic Factors

4.1.2.1 Hybridization

Hybridization of species is relatively rare in nature, but may be more common in fishes than in other vertebrates (Helfman 2007). Hybridization disrupts the gene complexes, often producing individuals less adapted to local conditions, if offspring to survive and reproduce with the parental species, introgression can occur (Helfman 2007).

Native southwestern sucker species are known to hybridize with each other, which is not considered a significant threat to the species. Razorback sucker x flannelmouth sucker hybrids have long been recognized (Jordan 1891; Hubbs and Miller 1953; Vanicek *et al.* 1970; Holden 1973; Tyus 1990; G. R. Smith 1992) and are known to back-cross with other catostomid species (M. E. Douglas and Marsh 1998). Razorback x flannelmouth hybrids are caught near annually across the UCRB in small numbers (STReAMS 2016). Overlap in habitat use by razorback sucker, flannelmouth sucker, and bluehead sucker occurs in the lower Grand Canyon and Colorado River inflow area to Lake Mead and hybrid native suckers have also been documented (Albrecht *et al.* 2014; Kegerries *et al.* 2015). In the upper Colorado River, razorback sucker x bluehead sucker hybrids have been collected, but are rare (Travis Francis, U.S. Fish and Wildlife

Service, personal communication, May 2018). There is no evidence of bluehead and razorback sucker hybridization in the San Juan River, despite abundant populations of bluehead sucker (Turner *et al.* 2002; Schleicher 2016).

Populations of nonnative white sucker *Catostomus commersonii* are expanding in the upper Colorado River basin, which may lead to increased rates of hybridization with razorback sucker. White sucker readily hybridize with native flannelmouth sucker and bluehead sucker in the Yampa River and the Green River in Lodore Canyon (Bestgen *et al.* 2017). Researchers document downstream expansion of white sucker into reaches where razorback sucker are attempting to reproduce, such as the middle Green River (Staffeldt *et al.* 2017a) and portions of the upper Colorado and lower Gunnison rivers (Francis and Ryden 2017); this expansion may increase the hybridization threat to razorback sucker.

4.1.2.2 Inbreeding Reducing Diversity

Inbreeding is a well-known cause of extinction in small populations as inbreeding depression and loss of heterozygosity undermine components of the population (M. E. Gilpin and Soule 1986). Genetic integrity was measured in all populations (data from the 1990's) and was found to be higher in lower basin populations (Dowling *et al.* 2012). These data were used to create genetically diverse broodstock for the upper basin that were then used as the foundation of current stocking efforts. Because most populations rely on stocking as a conservation tool, management of broodstock is essential to maintain natural levels of diversity (Dowling *et al.* 1996). Hatcheries have procedures in place to ensure continuation of documented genetic levels, but periodic genetic assessments should be completed.

Lake Mohave's population is managed as a genetic refuge for the species as diversity levels within that population exceed all other populations. Genetic integrity is assessed to ensure that management actions retain or improve genetic diversity in Lake Mohave (Turner *et al.* 2007; Dowling *et al.* 2014; Carson *et al.* 2016). A number of metrics are commonly evaluated to assess the genetic integrity of populations including N_e (the genetic effective population size) and N_b (the annual effective number of breeders) (Dowling *et al.* 2014). If all adults in a population breed every year and contribute genes to the following generation, some minimum number of adults (N_b) would equal N_e . However, as with most populations, it is believed that not all razorback suckers spawn every year or contribute genes to the following generation, and hence, N_b is likely not equal to N_e . Estimates of N_b are available for some populations (Diver and Wilson 2018), but many remain unmeasured. Genetic viability is increased through maintaining natural connectedness and potential for gene flow among populations, regardless of size (Rieman and Dunham 2000).

Current threats to the genetic diversity of razorback sucker populations are thought to be minimal, as most populations are managed through propagation and stocking, assuming genetic management protocols as applied in hatcheries are adequate and routinely evaluated. Should natural recruitment begin to occur, other threats to genetic diversity may emerge. Given the estimated genetic effective population size, the only self-sustaining and recruiting population in Lake Mead is not of sufficient size to maintain genetic diversity long-term, however the genetics of this population are being monitored.

4.1.3 Alterations to Habitat

4.1.3.1 Altered Flow Regime

Numerous researchers identified that one of the major factors contributing to the decline of razorback sucker throughout their ranges has been the construction of mainstem dams and the resultant cool tailwaters, altered flow regimes, and reservoir habitats that replaced a once warm, dynamic, riverine environment (Holden and Stalnaker 1975; Joseph *et al.* 1977; Wick *et al.* 1982; W. L. Minckley *et al.* 1991). This change in the physical environment allowed for an increase in competition and predation from nonnative fishes, which are successfully established in the Colorado River and its reservoirs, and has contributed to native fish population declines (W. L. Minckley *et al.* 1991). Although reservoirs have supported the proliferation of nonnative species, the resultant lentic habitat may provide suitable habitat for razorback sucker, as evidenced by population documented during the filling of Lake Mohave and the continued presence of a recruiting population in Lake Mead.

Flow regimes in the Colorado River basin have been modified by dams and diversions that suppress spring runoff peaks and increase summer and winter base flows. Since roughly 1962, changes in spring peak runoff and base flows are as follows (U.S. Fish and Wildlife Service 2017):

- Upper Colorado River: spring peak decreased 33% and base flow increased 37%
- Green River: spring peak decreased 34% and base flow increased 76%
- Yampa River: spring peak decreased 4% and base flow increased 5%
- Lower Colorado River: spring peak decreased 70% and base flow increased 258%
- San Juan River: spring peak decreased 46% and base flow increased 168% (Holden 1999)

In the San Juan system, these flow changes have altered habitat through bank armoring and facilitating the establishment of nonnative vegetation. These changes have reduced habitat complexity that support razorback sucker life history (Bliesner and Lamarra 2007; Bliesner *et al.* 2008; V. A. Lamarra and Lamarra 2013). In the UCRB, spring peaks are reduced and earlier because of storage of spring runoff, while channelization and levee placement have further reduced frequency and duration of floodplain inundation. Floodplain habitats are important for young razorback sucker growth and survival. Thus, a main factor limiting razorback sucker recruitment and recovery is related to floodplain wetland habitat availability, which is controlled by spring flow levels.

The flow regimes in the Lower Colorado River are highly regulated by dams and the need for water delivery. It is estimated that changes to points of water diversion in the lower basin move 1.574 million acre-feet per year and results in 399 surface area acres of backwater being lost in areas once used by razorback sucker (U.S. Department of Interior 2005). The Lower Colorado River Multi-Species Conservation Program (LCR MSCP) has conservation measures, which call for replacement, and management of these lost backwater habitats.

4.1.3.2 Land Use

Direct effects of land use are not a major risk to the condition of razorback sucker; that is, upland land use for agriculture, industrial, and municipal uses are not a primary risks to the species. The areas inhabited by razorback sucker are not densely populated by humans, and many stretches of river and reservoirs are protected by federal land ownership. Primary activities of upland land use are agricultural and energy development. These activities largely occur outside of river and reservoir habitats. Potential expansion of agriculture and further energy development in the basin could indirectly affect the species by increasing water use and decreasing flows available.

4.1.3.3 Reduced Water Temperature

The construction of mainstem dams created cool tailwaters unsuitable for egg and larval development. As noted above, rates of fish growth are dependent on the temperature at which they are reared (Bestgen 2008). Recruitment in cold, food-poor, high-velocity main channel habitat in spring is thought to be low in most years. However, recent collections of thousands of razorback sucker larvae in cold, Hoover Dam tailwaters near Willow Beach National Fish Hatchery are an apparent exception that should be noted (T. Delrose, LCR MSCP, email to LCRFish listserv, May 11, 2018).

Temperature recommendations and a temperature control device have been incorporated into the operation of Flaming Gorge Dam (Muth *et al.* 2000), but many mainstem systems remain impacted by cool tailwaters, including the Gunnison, San Juan and Colorado Rivers in the lower basin. Floodplain wetlands and backwaters are typically warmer than mainstem environments, underscoring their importance to early life stages of razorback sucker.

4.1.4 Nonnative Species

The introduction and proliferation of nonnative fishes create many direct and indirect impacts on native fishes of the southwestern United States, primarily from predation and competition but also through habitat alteration. Native fishes of the Colorado River basin appear to lack competitive and predator defense abilities compared to fishes that evolved in more species-rich regions (P. Martinez *et al.* 2014). The UCRB is currently occupied by approximately 50 nonnative fish species and the LCRB is occupied by approximately 20 nonnative species (Table 2) (Tyus *et al.* 1982; Lentsch *et al.* 1996; Valdez and Muth 2005). Several of these species present threats to razorback sucker at all life stages by preying on eggs, larvae, juveniles, and adults, competing for niche space, and altering the food web (Valdez and Muth 2005; Gozlan *et al.* 2010; P. Martinez *et al.* 2014).

4.1.4.1 Predation

Predation impacts most severely impact the larval to sub-adult life stages of razorback sucker. Outside of Lake Mead, and recent observations from the middle Green River in managed wetlands, there are few records of juvenile captures in the last 40 years. Because predation by nonnative fishes on young razorback sucker has been documented (Staffeldt *et al.* 2017a) and nonnative introduced predators are prevalent, predation at the larval and juvenile stages by nonnative piscivores is considered a major cause of low survival resulting in recruitment failure throughout the basin (Marsh *et al.* 2003; W. L. Minckley *et al.* 2003; Schooley, Karam *et al.* 2008; Ley *et al.* 2014; Ehlo *et al.* 2017). Expanding populations of smallmouth bass, flathead catfish, northern pike *Esox lucius*, striped bass *Morone saxatilis*, and channel catfish in reaches

where razorback sucker reproduce or are stocked may be a major obstacle to razorback sucker recruitment.

Contrastingly, depending on river reach and stocking history, annual adult survival has been estimated to be 70% or higher across the basin (Marsh *et al.* 2005; Zelasko *et al.* 2011; Zelasko *et al.* 2018). Evaluation of the upper basin stocking program from 2004 to 2007 demonstrated that size at stocking was positively correlated with survival (Zelasko *et al.* 2011), suggesting that predation risk is likely a large component of reduced survival of smaller individuals. Although predation by northern pike on larger stocked razorback sucker has been documented (pers. comm., K. Christopherson, Utah Division of Wildlife Resources), it does not seem to limit adult survival on a population scale. Additionally, abundant larvae have been produced annually in most reaches where adults occur; indicating that egg survival is not likely a limiting factor to razorback sucker.

Although predation pressure has likely limited razorback sucker recruitment for many decades, several examples suggest that recruitment of larvae to juvenile stages is possible under certain conditions, such as in managed pond and off-channel habitats free or relatively free of large bodied nonnative species. Locations with demonstrated survival of young life stages include Stewart Lake, (Green River subbasin in Utah), Imperial Ponds (lower Colorado River in Arizona), Cibola High Levee (lower Colorado River in Arizona) (W. L. Minckley *et al.* 2003; Schelly and Breen 2015; Schelly *et al.* 2016). Even in the absence of large-bodied nonnative predators, small-bodied nonnative fishes remain a concern. Predation on early life stages of catostomids in backwaters by green sunfish *Lepomis cyanellus* and red shiner *Cyprinella lutrensis* has been documented and doubtless also occurs in floodplain wetlands (Ruppert *et al.* 1993; Modde 1996; Christopherson *et al.* 2004; Modde and Haines 2005).

Although all nonnative fish species are problematic, research identified northern pike, smallmouth bass, and walleye *Sander vitreus* as the most problematic in the lotic portions of the Green and Colorado subbasins because of their high abundance, habitat use that overlaps with most native fishes, and ability to consume a wide variety of life stages of native fishes (Johnson *et al.* 2008; P. Martinez *et al.* 2014). Channel catfish *Ictalurus punctatus* are the most abundant lotic nonnative piscivorous fish in the San Juan basin, but recent studies have not documented population level effects on razorback sucker (Franssen *et al.* 2014).

Table 2. Nonnative fishes present in the upper and lower Colorado River basins and their relative abundance. (UCRB,data recreated from Valdez and Muth 2005).

Species	Scientific Name	UCRB	LCRB	Relative Abundance
Catostomidae (suckers)				
Utah sucker	<i>Catostomus ardens</i>	X		Common in some reservoirs; incidental-to-rare in some river reaches
longnose sucker	<i>C. catostomus</i>	X		Incidental-to-rare in some river reaches
white sucker	<i>C. commersonii</i>	X		Common in some reservoirs; locally common in some river reaches
Centrarchidae (sunfishes)				
green sunfish	<i>Lepomis cyanellus</i>	X	X	Locally common
bluegill	<i>L. macrochirus</i>	X	X	Common in some reservoirs; incidental-to-rare in some river reaches
redeer sunfish	<i>L. microlophus</i>		X	Common in Lake Havasu
smallmouth bass	<i>Micropterus dolomieu</i>	X	X	Abundant in some reservoirs; common-to-abundant in some river reaches
largemouth bass	<i>M. salmoides</i>	X	X	Abundant in some reservoirs; incidental-to-rare in some river reaches
white crappie	<i>Pomoxis annularis</i>	X		Incidental
black crappie	<i>P. nigromaculatus</i>	X	X	Abundant in some reservoirs; incidental-to-rare in some river reaches
Cichlidae (cichlids)				
blue tilapia	<i>Oreochromis aureus</i>		X	Incidental-to-locally common
Clupeidae (herrings)				
gizzard shad	<i>Dorosoma cepedianum</i>	X	X	Abundant in reservoirs, becoming more common in riverine reaches
threadfin shad	<i>D. petenense</i>	X	X	Common in reservoirs and tributary inflows
Cyprinidae (minnows)				
goldfish	<i>Carassius auratus</i>	X		Incidental
grass carp	<i>Ctenopharyngodon idella</i>	X		Incidental
red shiner	<i>Cyprinella lutrensis</i>	X	X	Widespread, common-to-abundant
common carp	<i>Cyprinus carpio</i>	X	X	Widespread, common-to-abundant; uncommon in San Juan River
Utah chub	<i>Gila atraria</i>	X		Abundant in Flaming Gorge Reservoir; incidental-to-rare in some river reaches
brassy minnow	<i>Hybognathus hankinsoni</i>	X		Incidental
plains minnow	<i>H. placitus</i>	X		Incidental
Southern leatherside chub	<i>Lepidomeda aliciae</i>	X		Incidental

Species	Scientific Name	UCRB	LCRB	Relative Abundance
golden shiner	<i>Notemigonus crysoleucas</i>	X		Incidental
sand shiner	<i>Notropis stramineus</i>	X		Common-to-abundant
fathead minnow	<i>Pimephales promelas</i>	X	X	Widespread, common-to-abundant
bullhead minnow	<i>P. vigilax</i>	X		Incidental
longnose dace	<i>Rhinichthys cataractae</i>	X		Incidental
redside shiner	<i>Richardsonius balteatus</i>	X		Rare-to-common in upper reaches of some rivers
creek chub	<i>Semotilus atromaculatus</i>	X		Incidental-to-rare
Cyprinodontidae (killifishes and pupfishes)				
plains topminnow	<i>Fundulus sciadicus</i>	X		Incidental
plains killifish	<i>F. zebrinus</i>	X		Incidental
rainwater killifish	<i>Lucania parva</i>	X		Incidental
Esocidae (pikes)				
northern pike	<i>Esox lucius</i>	X		Abundant in Yampa River, common in Upper Green, rare elsewhere in UCRB
Gadidae (cods)				
burbot	<i>Lota lota</i>	X		Incidental in Flaming Gorge Reservoir and river upstream
Gasterosteidae (sticklebacks)				
brook stickleback	<i>Culaea inconstans</i>	X		Locally incidental
Ictaluridae (catfishes)				
black bullhead	<i>Ameiurus melas</i>	X	X	Incidental-to-locally common
yellow bullhead	<i>A. natalis</i>	X	X	Common in reservoirs
brown bullhead	<i>A. nebulosus</i>	X		Incidental
flathead catfish	<i>Pylogictis olivaris</i>		X	Common in Lake Havasu, and below Parker Dam
channel catfish	<i>Ictalurus punctatus</i>	X	X	Widespread, common-to-abundant
vermiculated sailfin catfish	<i>Pterygoplichthys disjunctivus</i>		X	Localized and incidental
Moronidae (temperate basses)				
white bass	<i>Morone chrysops</i>	X		Incidental-to-rare
striped bass	<i>M. saxatilis</i>		X	Abundant in reservoirs/tributary inflows
Percidae (perches)				
Iowa darter	<i>Etheostoma exile</i>	X		Incidental
Johnny darter	<i>E. nigrum</i>	X		Incidental

Species	Scientific Name	UCRB	LCRB	Relative Abundance
yellow perch	<i>Perca flavescens</i>	X		Common in some reservoirs; incidental-to-rare in some river reaches
walleye	<i>Sander vitreus</i>	X		Common in some reservoirs; common in some river reaches
Poeciliidae (livebearers)				
western mosquitofish	<i>Gambusia affinis</i>	X	X	Incidental to locally common
Salmonidae (trout and salmon)				
Yellowstone cutthroat trout	<i>Oncorhynchus clarkii bouvieri</i>	X		Incidental-to-rare in cool streams
greenback cutthroat trout	<i>O. c. stomias</i>	X		Incidental-to-rare in cool streams
coho salmon	<i>O. kisutch</i>	X		Common in some cold reservoirs
rainbow trout	<i>O. mykiss</i>	X	X	Rare-to-common in cool river reaches; actively stocked
Kokanee	<i>O. nerka</i>	X		Common in cold reservoirs
brown trout	<i>Salmo trutta</i>	X	X	Rare-to-common in cool river reaches
brook trout	<i>Salvelinus fontinalis</i>	X		Rare-to-common in cool streams
lake trout	<i>S. namaycush</i>	X		Abundant in some cold reservoirs

Large-bodied predators emerged in the UCRB as threat approximately 25 years ago, as species introduced for sportfishing opportunities began to colonize river habitats, primarily by escaping from reservoirs in which they were stocked. Populations of northern pike expanded in the Yampa River in the 1990s; smallmouth bass increased in abundance in the Yampa River after persistent drought in the early 2000s with subsequent colonization of other habitats in the Green, Duchesne, White, and Colorado rivers during drought conditions in the early 2000s (Hawkins *et al.* 2005; Breton *et al.* 2013). Since approximately 2008, walleye have established relatively high densities in razorback sucker nursery habitats of the lower and middle Green River and the lower portions of the upper Colorado River (Francis and Ryden 2014; Francis and Ryden 2015; Jones, Haines *et al.* 2015; Schelly and Breen 2015a). Drought conditions in the early 2000s caused Lake Powell to recede and a waterfall to form, blocking access of all fishes to the San Juan River. Nonnative removal in the San Juan River has primarily focused on reducing populations of common carp *Cyprinus carpio* and channel catfish; carp have dramatically declined in response, but a large, resident channel catfish population persists (Hines 2015; Pennock *et al.* 2018).

Reservoir habitats are dominated by nonnative fishes, primarily managed as sportfishing opportunities. For example, Lake Powell is inhabited primarily by nonnative predatory sport fish, such as walleye and striped bass, which may pose considerable limitations to in-lake razorback sucker recruitment (Albrecht *et al.* 2017). However, recruitment within Lake Mead suggest that recruitment is possible, even in the presence of nonnative fishes (Albrecht *et al.* 2010; Mohn *et al.* 2015).

As in the UCRB, predation by and competition with nonnative fish species are major threats to razorback sucker recruitment in the LCRB. Approximately 20 nonnative fish species (Table 2) species occupy razorback sucker habitats, both in riverine and reservoir environments, with varying impacts to razorback sucker individuals. While larval and juvenile razorbacks are vulnerable to predation by nearly all introduced fishes, certain species impact larger life stages. For example, flathead catfish prey on razorback suckers of all sizes, and likely preclude the establishment of razorback sucker populations in areas where they are widespread and abundant (such as the Verde River and Colorado River downstream from Lake Havasu).

Predation of native fish by catfish, trout, and striped bass has been documented in the Grand Canyon (Kaeding and Zimmerman 1983; Valdez and Ryel 1995; M. E. Douglas and Marsh 1996; C. O. Minckley 1996; Valdez and Carothers 1998), but is thought to be a low risk to razorback sucker that inhabit areas dominated by native fishes. However, over the past 5 years, native fish have been dominant in the Grand Canyon below the Little Colorado River inflow. Furthermore, recent sampling below Lava Falls reports small-bodied nonnative abundance in nearshore habitats to be less than 12% of the total (Albrecht *et al.* 2014b; Kegerries *et al.* 2015a). Because of an apparent lack of diverse food items and a longitudinal pattern in food-web dynamics (Cross *et al.* 2013), it is likely that competition among all fish species is occurring, demonstrating that competition with other native fishes can be a consideration as well. The threat of nonnative fishes in the Grand Canyon is not certain to remain low. In fact, escapement of nonnative fishes from Lake Powell through the dam penstocks and generators of Glen Canyon Dam has been projected to possibly increase as reservoir elevation becomes lower and warm epilimnetic water is entrained (U.S. Department of the Interior 2010).

The fish communities in the river arms of Lakes Powell and Mead, where populations of razorback sucker are concentrated, consist of over 20 fish species as assessed through trammel netting efforts (data from Albrecht *et al.* 2017) (Figure 6). All but four of those species (razorback sucker, flannelmouth sucker, bluehead sucker, and Colorado pikeminnow) are nonnative fish. At each location, razorback sucker made up a small percentage of the total catch, but were as abundant as other native suckers. Gizzard shad *Dorosoma cepedianum*, common carp, bluegill *Lepomis macrochirus*, channel catfish, striped bass, smallmouth bass, and largemouth bass *Micropterus salmoides* were the most abundant species, demonstrating the dominance of nonnative species in these habitats (data from Albrecht *et al.* 2017).

2006; Karam and Marsh 2010). Striped bass, as well as sunfish, may play a role in population declines throughout Lake Mohave (Karam and Marsh 2010; Kesner *et al.* 2012); predation of a 500 mm razorback sucker by striped bass was documented when an angler found an acoustic transmitter in a striped bass stomach. Sunfish have been implicated in lack of survival of young razorback sucker.

Lake Havasu is managed as a sport fishery by the state of Arizona, which supports populations of largemouth bass, smallmouth bass, striped bass, bluegill, and redear sunfish. Other nonnatives present in Lake Havasu, but which are not actively managed, include green sunfish, yellow bullhead *Ameiurus melas*, flathead catfish, and channel catfish.

Predation by nonnative catfish was studied in the Gila River, documenting predation of multiple razorback sucker by 55% of channel catfish and 90% of flathead catfish studied (Marsh and Brooks 1989). Thus, in the Gila River, predation likely accounts for the poor success of razorback sucker repatriation (Marsh and Brooks 1989). Additionally, short-term mortality and the lack of long-term survival in the Colorado River below Parker Dam due to predation by fish (including flathead catfish) and birds led to a recommendation to limit stocking to only predator-free habitats (Schooley, Kesner *et al.* 2008). Stocking efforts were eventually abandoned in the basin as no evidence of long-term survival was found.

4.1.4.2 Competition

Nonnative species have a variety of traits that allow them to effectively compete for niche space, including a lack of dependence on fluvial conditions to complete the life cycle, preference for slow currents and warm water, omnivorous behavior, variable spawning substrate requirements, maturation at an early age and smaller size, production of smaller eggs that hatch quickly, and larger swim factors (Olden *et al.* 2006). Razorback sucker have similar characteristics in a preference for slow and warm currents and a wide diet breadth, opening them to competition from a variety of species including common carp and channel catfish (Olden *et al.* 2006). Competition between native and nonnative species is known to occur in the Colorado River basin (Tyus and Saunders 2000; Carpenter 2005), but there is little information documenting the effect of competition isolated from predation. For example, red shiner and fathead minnow *Pimephales promelas* are common in backwaters and floodplains and are thought to be of concern because of their aggressive nature (Karp and Tyus 1990; Tyus and Saunders 2000), but are also known to prey on larval razorback sucker.

4.1.4.3 Habitat effects

Habitat is affected by invasions of both plant and animal species, with varying effects depending on the invasive species. Riparian habitats are considered especially prone to invasion by plant species, which can alter both the hydrology and fluvial geomorphology of a riverine system (Tickner *et al.* 2001). After dam construction and the elimination of large flood events, Tamarix species expanded across the western U.S. corresponding with substantial decreases in visible sandbars and gravel in stream channels (Brock 1994). Invasive aquatic species such as common carp or dreissenid mussels can also affect habitat by modifying water quality and trophic structures (Higgins and Zanden 2010; Kloskowski 2011). Although invasive species have altered habitat throughout the Colorado basin, the effects on razorback sucker are thought to be limited in comparison to predation.

4.1.5 Overutilization

Although early historical reports razorback sucker as being harvested in great quantities by fishing (W. L. Minckley 1973), razorback sucker are not currently used for commercial, recreational, or educational purposes. Razorback sucker are protected by state fishing regulations, requiring anglers to return individuals to the water upon catch (New Mexico Department of Game and Fish 2016; Colorado Parks and Wildlife 2018; Utah Division of Wildlife Resources 2018; Nevada Department of Wildlife 2018; Arizona Game and Fish Department 2018). The impacts of electrofishing and associated handling occurring throughout the basin (for both research/monitoring and nonnative fish removal) could be affecting the razorback sucker, especially during spawning. Protocols for sampling in the UCRB have been refined to limit fish stress, and electrofishing is prohibited on active spawning locations.

4.1.6 Parasites and Diseases

Common ailments among razorback sucker populations include a host of parasites (protozoans, parasitic worms, and copepods) and blindness (W. L. Minckley *et al.* 1991). Asian tapeworm *Bothriocephalus acheilognathi* has been detected in nonnative species in the Little Colorado River basin, which joins with the Colorado River in the Grand Canyon (Stone *et al.* 2007). Further studies indicate it may be present in the upper Colorado River basin as well (Choudhury *et al.* 2006). Parasites and disease are thought to be of limited concern for razorback sucker recovery (W. L. Minckley *et al.* 1991).

4.1.7 Pollutants

Natural and human factors such as climate, geology, soils, water management, and land use affect water quality. In general, water temperature, sediment, salinity, nitrogen, and phosphorus concentrations increase from upstream to downstream within the basin. A number of contaminants enter the Colorado River on a regular basis from municipal, industrial, historical mining and agricultural sources. Discharges from municipal and industrial sources are regulated by permit and must meet state and federal instream water quality standards, including standards protecting the most sensitive aquatic species. Water quality standards for permitted municipal and industrial discharges into habitat of endangered species are subject to consultation under the ESA to ensure protection of endangered species. Unregulated discharges, such as historical mining sites are present throughout the basin and have been mapped and quantified for some subbasins (Church 2007).

4.1.7.1 Metal Toxicity

Selenium naturally occurs in the environment and is required for normal growth and development; however, elevated levels can have detrimental effects. If selenium bioaccumulates, toxic levels can cause deformities and decreased reproductive success in fish (Hamilton 2004). Selenium has been documented in high concentrations in mainstem and wetland habitats of the UCRB since the 1930s, and its adverse biological effects on both larvae and adult razorback sucker have been documented (Hamilton 1998; B. C. Osmundson *et al.* 2000).

Considerably more selenium is found in the Colorado River above the Green River confluence than in the Green and San Juan river basins of the UCRB. Selenium remediation has been implemented in the Gunnison River, and sources of selenium have been identified within the Green River (e.g., Stewart Lake; (U.S. Fish and Wildlife Service 2017)).

The LCRB contains some of the highest selenium concentrations in the nation (Radtke *et al.* 1988; Hamilton 1998). Fish tissue samples from Lake Mead, Lake Havasu, Imperial Reservoir, and the Colorado River near Yuma exceeded water quality standards for selenium concentration. Samples from the Gila River (San Carlos Reservoir) did not, assessed at the 85th percentile of concentrations measured. Elevated concentrations of selenium are found near Imperial Dam (Engberg 1999). In the LCRB, reservoir and backwater habitats have been and continue to be monitored for water quality purposes.

4.1.7.2 Runoff Pollution

Runoff pollution is caused when rainfall or snowmelt, moving over the ground, picks up natural or man-made pollutants, depositing them into nearby waterbodies. Runoff from agricultural and undeveloped areas are not managed through the discharge permitting process and are therefore unregulated. Little is known about the full suite of compounds and chemicals present in runoff throughout the basin, but a few studies have been conducted to examine the impacts of certain activities on certain in-stream loads. Oil and gas development in the basin are expected to have little effect on dissolved-solid loads in comparison to undisturbed land (Buto *et al.* 2010). Irrigation and its associated runoff are thought to be responsible for 71% of the selenium reaching Lake Powell (Engberg 1999). Although mostly meeting state and federal water-quality guidelines, exceedances of trace elements (cadmium, zinc, copper, lead and selenium) do occur across the basin (Spahr 2000). Elevated levels of selenium, mercury, and pesticides have been found in nonnative fish samples from across the Colorado River basin (Hinck *et al.* 2007). The study also documented the presence of intersex fish, which may indicate presence of endocrine disrupting compounds (Hinck *et al.* 2007). The effects of current or emerging contaminants on reproductive success or health of razorback sucker is unknown.

4.1.7.3 Contaminant Spills

Catastrophic spills of hazardous materials, such as petroleum products or other chemicals are a potential threat to water quality throughout the Colorado River basin. The Denver and Rio Grande Western railroad tracks have paralleled the Colorado River at Black Rocks and upper Westwater Canyon since ~1883 (Bradley 1996); these pose a risk of derailment and spills of materials into the river, although no known derailment has occurred in these areas. Numerous petroleum-product pipelines cross or parallel rivers in the upper basin. Existing and future oil and gas wells located near floodplains, arroyos, or washes are another potential spill source. The susceptibility of habitats to these spills is demonstrated by the 2014 well rupture near Green River, UT that spilled petroleum compounds into the Green River where razorback sucker are common². HAZMAT plans exist for states of the Colorado River basin, but have not been reviewed or evaluated to determine how they would be implemented to mitigate contaminant spills.

² <http://www.moabsunnews.com/news/article ce055ca4-e673-11e3-be35-001a4bcf6878.html>

Ash or debris flows from large rainstorms following rangeland fires are a more natural catastrophic threat to razorback sucker in the basin. These flows can deliver large amounts of mud, ash, and debris that can suffocate fish and macroinvertebrates; these debris flows often occur after fires have denuded the landscape of vegetation and may contain fire retardant chemicals that could cause toxic fish effects. Wildfires have been shown to liberate accumulated heavy metals and increase nutrient loading into streams (Bladon *et al.* 2014).

4.2 Ongoing and Future Conservation Actions

The following four programs in the Colorado River basin are designed to balance demands for water and power while protecting natural resources and conserving and/or recovering endangered fish, including razorback sucker.

- The Upper Colorado River Endangered Fish Recovery Program (UCREFRP) is recovering the humpback chub, Colorado pikeminnow, razorback sucker, and bonytail upstream of Lake Powell. The program was established in January 1988. The UCREFRP is a unique partnership of local, state and federal agencies, water and power interests and environmental groups. The program is authorized through 2023. Recovery efforts for razorback sucker are implemented each year through the Program's annual budgeting and work plan process. Specific activities are defined in the Recovery Implementation Program/Recovery Action Plan (RIP/RAP), including augmentation, flow and habitat management, nonnative fish control and monitoring consistent with the razorback sucker Recovery Plan (U.S. Fish and Wildlife Service 2002).
- The San Juan River Basin Recovery Implementation Program (SJRIP) is recovering the Colorado pikeminnow and razorback sucker and is specific to the San Juan River, including the San Juan River arm of Lake Powell. The program was established in 1992 and is funded through 2023. All recovery efforts for razorback sucker are outlined each year through this program's Long-Range Plan (San Juan River Basin Recovery Implementation Program 2016).
- The Glen Canyon Dam Adaptive Management Program (GCDAMP) was established in 1997 and coordinates research and monitoring activities aimed at protection of natural resources of the Colorado River through the Grand Canyon, including activities to benefit the humpback chub and razorback sucker from Glen Canyon Dam to the Lake Mead inflow. The GCDAMP is not a recovery program but instead makes recommendations to the Secretary of the Interior in compliance with the Grand Canyon Protection Act and environmental commitments for operation of Glen Canyon Dam. The funding is currently legislated without sunset (U.S. Department of the Interior 2016).
- The Lower Colorado River Multi-Species Conservation Program (LCR MSCP) is a partnership of federal and non-federal stakeholders created in 2005 to respond to the need to balance the use of lower Colorado River (LCR) water resources and the conservation of native species and their habitats in compliance with the Endangered Species Act (ESA). The program coordinates conservation of multiple species, including the

humpback chub, razorback sucker, and bonytail, from the Lake Mead inflow to the border with Mexico. The program provides ESA compliance through a Habitat Conservation Plan, where actions provided by the program address adverse effects on covered species that may result from all federal and non-federal actions that occur in the geographic area of the program (U.S. Department of Interior 2005). This program is currently set to expire in 2055 and annual work plans, budgets, and progress reports document efforts directed towards conservation of razorback sucker and other species.

Other smaller programs, funding sources, or conservation entities include the Gila River Basin Conservation Program, the Salt River Project's Horseshoe-Bartlett Habitat Conservation Plan (helps to support conservation in the Verde River), the Lake Mohave Native Fish Workgroup, the Lake Mead Razorback Sucker Workgroup, and other similar working groups.

The 2002 recovery goals for razorback sucker (U.S. Fish and Wildlife Service 2002) outline the need for conservation agreements to be in place as delisting occurs, emphasizing the importance of management to this and other species.

Conservation plans will go into effect at delisting to provide for long-term management and protection of the species, and to provide reasonable assurances that recovered razorback sucker populations will be maintained without the need for relisting. Elements of those plans could include (but are not limited to) provision of flows for maintenance of habitat conditions required for all life stages, regulation and/or control of nonnative fishes, minimization of the risk of hazardous-materials spills, and monitoring of populations and habitats. Signed agreements among State agencies, Federal agencies, American Indian tribes, and other interested parties must be in place to implement the conservation plans before delisting can occur.

The UCREFRP, SJRIP, GCDAMP, and LCR MSCP have implemented a suite of actions that benefit a variety of species. Many actions specific to razorback sucker match fourteen actions deemed necessary in the 2002 recovery goals:

1. Reestablish populations with hatchery-produced fish.
2. Identify and maintain genetic variability of razorback sucker in Lake Mohave.
3. Provide and legally protect habitat (including flow regimes necessary to restore and maintain required environmental conditions) necessary to provide adequate habitat and sufficient range for all life stages to support recovered populations.
4. Provide passage over barriers within occupied habitat to allow unimpeded movement and, potentially, range expansion.
5. Investigate options for providing appropriate water temperatures in the Gunnison River.
6. Minimize entrainment of subadults and adults at diversion/out-take structures.
7. Ensure adequate protection from overutilization.
8. Ensure adequate protection from diseases and parasites.
9. Regulate nonnative fish releases and escapement into the main river, floodplain, and tributaries.
10. Control problematic nonnative fishes as needed.
11. Minimize the risk of hazardous-materials spills in critical habitat.

12. Remediate water-quality problems.
13. Minimize the threat of hybridization with white sucker.
14. Provide for the long-term management and protection of populations and their habitats beyond delisting (i.e., conservation plans).

Below is a general summary of conservation actions implemented by these programs, ranked as most impactful to razorback sucker (Delphi process, Appendix A). Actions that were not called out in the Delphi process are noted under Program Management and Funding (Section 4.2.2)

4.2.1 Water Management

The UCREFRP and the SJRIP continue to work with partners to adaptively manage flows to benefit razorback sucker and other native fishes. Flow recommendations have been developed for most major rivers of the UCRB (Holden 1999; Muth *et al.* 2000; McAda 2003), coupled with temperature recommendations in the Green River. These recommendations are evaluated through a series of UCREFRP and SJRIP studies that are coordinated through study plans (ad hoc Committee 2007; ad hoc Committee 2011). Technical committees evaluate each study and recommend further actions through the programs' annual planning documents.

Flow recommendations for Flaming Gorge are specified by reach, by condition and by hydrologic condition (Muth *et al.* 2000). Temperature recommendations are in place in Reach 1 (above the confluence with the Yampa River) and recommend less than 5 C difference between the Green River and the Yampa River to prevent thermal shock (Muth *et al.* 2000). In addition, spring flow management (larval trigger study plan [LTSP]) in the middle Green River has been refined in recent years by timing spring peak releases to better coincide with real-time emergence of larval razorback sucker, which helps entrain them into flooded wetland habitats (Bestgen *et al.* 2011; LaGory *et al.* 2012). Floodplain wetlands are warm, food-rich floodplain areas, which are likely important rearing and resting habitat for early and adult life stages of spring-spawning razorback sucker, and may enhance recruitment (Modde *et al.* 1996; Muth *et al.* 1998; Bestgen *et al.* 2002; Bestgen *et al.* 2011). Since implementation in 2012, results of LTSP have been largely positive and the survival of age-0 razorback sucker into the winter is now frequently documented at Stewart Lake (Schelly *et al.* 2014; Schelly and Breen 2015; Schelly *et al.* 2016; Staffeldt *et al.* 2017b). Efforts to improve the function of other UCRB wetlands are ongoing.

Various water agreements and coordinated water management activities have been implemented in the upper Colorado River basin to augment flows along key river reaches for the benefit of endangered fish, including razorback sucker. These include measures to augment annual spring high flows in the Green, Gunnison, and mainstem Colorado Rivers (see Section 5.1.2), and to augment late-summer base flows in these rivers, as well as the Yampa and Duchesne rivers. Since 1998, more than 1.5 million acre-feet of water has been delivered to the 15-Mile Reach of the mainstem Colorado River pursuant to various agreements and commitments for base flow augmentation during the July-through-October low-flow season. Similarly, the U.S Bureau of Reclamation's (Reclamation) modified reservoir operations for their Aspinall Unit dams (U.S. Fish and Wildlife Service 2009a) and Flaming Gorge Dam (U.S. Department of Interior 2006) have collectively resulted in the augmentation and/or re-timing of millions of acre-feet of

instream flow to benefit the endangered fish and their habitats. All flow enhancements are voluntary.

Along with these flow augmentation and flow re-timing actions, the UCREFRP has also helped fund and facilitate projects in the Upper Basin, which improved water management and allowed for more precise control over water diverted into irrigation systems. For example, extensive improvements in irrigation efficiencies have been realized since the late 1990's by two large irrigation districts in the Grand Valley of Colorado: the Grand Valley Water Users Association and the Orchard Mesa Irrigation District, in part through UCREFRP funding. These improvements include miles of lined canals, multiple check dams, reregulating reservoirs, and computer-based ("SCADA") systems for better real-time monitoring and control of irrigation diversions and deliveries. Collectively, these improvements leave water undiverted or returned to the mainstem of the Colorado River and its upstream reservoirs, often amounting to tens of thousands of acre-feet annually, allowing this water to be bypassed or delivered at times and places that better satisfy the flow targets for the endangered fish. Similarly, improvements made in 2017 to the headgate and delivery canals associated with the Maybell Irrigation District's irrigation system along the Yampa River should substantially reduce occurrences of over-diversion from that river, leaving more instream flow to benefit fish.

In the Grand Canyon, Glen Canyon Dam, releases are coordinated through operating criteria outlined in the Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations of Lake Powell and Lake Mead Environmental Impact Statement (EIS) (U.S. Department of the Interior 2007), with additional guidance for resource protection by the Long-Term Experimental and Management Plan EIS (U.S. Department of the Interior 2016). All other dams in the lower basin are managed for hydropower.

4.2.2 Program Management and Funding

Authorizing legislation for all four programs and financial commitments from their partnering entities currently provide funding for the three components identified above and below (i.e. 4.2.1, 4.2.3 – 4.2.5) as well as additional actions deemed important by the programs.

The UCREFRP and SJRIP are staffed by U.S. Fish and Wildlife Service employees, but work is prioritized using committee structures comprised of representatives from other federal agencies, states, water users, and environmental groups (and Tribal representatives in the SJRIP). Between 1989 and 2018, the UCREFRP spent over \$394 million dollars on recovery actions including habitat restoration, nonnative fish management, research and monitoring, propagation and genetics management, instream flow protection and education and outreach. Between 1992 and 2018, the SJRIP spent over \$78 million dollars on similar projects. Both programs are funded by power revenues from Western Area Power Administration, Reclamation, the U.S. Fish and Wildlife Service, participating states, and other partners specific to each program. The funds are spent on capital projects like fish screens, passage devices or habitat modifications as well as annually funding perpetual activities such as monitoring or nonnative fish removal (Fischer 2018).

All four programs provide some measure of protection or improvement of habitats occupied by razorback sucker. Habitats occupied by razorback sucker fall under the management of all federal land management agencies and various Native American Tribes. Critical habitat has been designated for the species in the UCRB and LCRB (including reaches in the Gila basin), requiring federal agencies to consult with USFWS before modifications can be made. Several floodplain habitats have been developed in the Green River subbasin including Stewart Lake, Johnson Bottom, and Sheppard Bottom and are managed to entrain larval razorback sucker in conjunction with LTSP, all of which are located close to Vernal, Utah. Additional habitats are being explored for development in the basin (Speas *et al.* 2017). Habitat restoration activities involving modification of floodplain wetlands for razorback sucker use are currently being considered in the Colorado River near Moab, UT and in the San Juan River.

Fish-passage structures have been installed on the Gunnison, upper Colorado, Green, and San Juan rivers. These structures allow native fish to access the upstream reaches of their historical ranges and could allow for population increases and expansions, providing water temperatures are adequate. Fish screens or weir walls have been installed in canals in the upper basin to reduce entrainment of fish in the Gunnison, upper Colorado, Green, and San Juan rivers. These structures reduce the loss of native fishes when water is released onto fields for irrigation and the fish otherwise become stranded in seasonally dried canals. The remaining open canal on the Green River is scheduled to be screened in 2019.

LCR MSCP management is housed in Reclamation in Boulder City, Nevada. The program's estimated cost is \$626 million (in 2003 dollars), which is paid for by the Federal Government and the states of Arizona, California and Nevada (Lower Colorado River Multi-species Conservation Program 2018). The program is focused on creating at least 8,132 acres of new habitat (5,940 acres of cottonwood-willow, 1,320 acres of honey mesquite, 512 acres of marsh, and 360 acres of backwater) and producing 660,000 subadult razorback suckers and 620,000 bonytail to augment the existing populations of these fishes in the LCR. Under the LCR MSCP, participation in the recovery programs for these fishes may also include funding other appropriate activities in lieu of stocking. In addition, there is a substantial research and monitoring component to this program; a \$25 million fund was established to support projects implemented by land use managers to protect and maintain existing habitat for covered species (Lower Colorado River Multi-species Conservation Program 2018).

Conservation areas that are being developed by LCR MSCP primarily as disconnected backwaters for native fishes, prioritize (1) delivery of non-native fish-free replacement water and (2) the ability to completely drain and renovate ponds without the use of piscicides (Lower Colorado River Multi-species Conservation Program 2018). There is also value in connected backwaters, and the creation of connected backwaters is an option in Reaches 3–5. Restoration research priorities for backwater development are expected to include researching water screening to exclude non-native fishes, maintaining water quality in isolated backwaters, and controlling non-native fish species (Lower Colorado River Multi-species Conservation Program 2018).

4.2.3 *Nonnative Removal and Control*

The UCREFRP and the SJRIP are working to reduce the numbers of nonnative fishes, focusing primarily on smallmouth bass, northern pike and walleye in the Green and upper Colorado subbasins and channel catfish in the San Juan. A comprehensive nonnative fish control strategy was developed by the UCREFRP encompassing active removal from riverine habitats, escapement prevention from upstream reservoirs, revised stocking guidelines, harvest regulation changes, and outreach messaging (P. Martinez *et al.* 2014). In 2018, nonnative fish removal was the second largest expenditure made by the UCREFRP behind habitat restoration. In-river removal, the primary threat reduction action taken by the UCREFRP and the SJRIP has been evaluated (Breton *et al.* 2014; Franssen *et al.* 2014; Zelasko *et al.* 2015; Pennock *et al.* 2018). Removal programs in the UCREFRP are being adjusted annually (i.e., level of effort, spatial allocation, target species, etc.) as appropriate.

Although efforts to reduce the number of smallmouth bass show potential for successful reduction (Breton *et al.* 2014), removal efforts may need to continue as long as source populations exist. Catch rates have declined in recent years, but vary depending on local environmental conditions; smallmouth bass continue to recruit in high numbers during low water years (U.S. Fish and Wildlife Service 2017). Efforts continue to suppress populations but are unlikely to eliminate populations without more effective and innovative solutions. Recent efforts have focused on the potential use of dramatic increases in flow or turbidity during smallmouth bass spawning periods, for reach-wide population effects. A spike in flow associated with a thunderstorm over the Yampa River watershed in 2015 prevented recruitment of an entire year class of smallmouth bass through larval displacement and nest abandonment by males (Bestgen *et al.* 2018).

Efforts to reduce and remove northern pike will also need to be expanded to positively impact the native fish community (Zelasko *et al.* 2015). Reducing in-river reproduction and source emigration as a means to successfully controlling populations has been recommended (Breton *et al.* 2014; Zelasko *et al.* 2015). In recent years, fyke nets have been deployed in tributary mouths during spawning seasons for northern pike, which has removed hundreds of pike with relatively little effort when compared to electrofishing. Catch rates have declined to just over 100 fish in that reach in 2017, indicating that new gill-netting techniques are also helping in backwaters and tributary mouths to decrease pike populations (C. T. Smith and Jones 2017).

UCREFRP has recently focused on the installation of escapement-prevention devices at upstream reservoirs, such as Elkhead, Rifle Gap, Highline Lake, Starvation, Ridgway, and Lake Nighthorse, and the eradication of illegally introduced populations of walleye and smallmouth bass, such as those at Paonia, Miramonte, and Red Fleet reservoirs. Annual surveys show a marked decrease in nonnative fishes below escapement devices, in some cases eliminating northern pike and smallmouth bass in downstream waters (Felt 2018). The Elkhead Screen was installed in 2016. After one year of operation, largemouth and smallmouth bass were found in both the spillway site and the stilling basin, but northern pike were not (A. Martinez *et al.* 2017). The screen is to be inspected annually, and fishing surveys will document the presence of fish behind the net and in spillway canals. To date, complete containment has not been obtained.

Over the past 3–5 years, walleye removal efforts in the Green and Colorado have not resulted in a decline in adult catch rates (Michaud *et al.* 2016). Efforts are currently ongoing to perform otolith microchemistry analyses to determine origin of walleye collected in the upper Colorado River subbasin (Michaud *et al.* 2016). Lake Powell is hypothesized to be a source, as populations of walleye and gizzard shad (a main food source) are expanding in the reservoir.

Currently, San Juan River nonnative-control efforts focus on removing channel catfish and common carp. Since 2011 more than 138,000 channel catfish and 800 common carp have been removed during SJRIP nonnative-control efforts (Duran *et al.* 2013; Gerig and Hines 2013; Duran 2014; Hines 2014; Hines 2015; Duran 2016; Hines 2016). In 2016, the SJRIP implemented a new control-treatment design to evaluate the effects of nonnative fish removal. A draft report indicates that current removal efforts are likely too low to cause measurable effects on catch per unit effort or population abundance, but are having measurable effects on the size structure of the population (Franssen *et al.* 2014; Duran 2016; Pennock *et al.* 2018).

Procedures for stocking nonnative fishes have been developed and agreements have been signed between the USFWS and the states of Colorado, Utah, and Wyoming for the Green River and upper Colorado River subbasins (U.S. Fish and Wildlife Service 2009b). These procedures identify the measures necessary to fully evaluate any species stocked into state waters and ensure that these species will not threaten native species. Similar efforts are underway in the San Juan River subbasin.

Fish harvest regulations (P. Martinez *et al.* 2014) have been updated in the states of Utah, Wyoming, and Colorado to limit abundance and encourage take of problematic nonnative species and prevent new introductions. For example, burbot *Lota lota*, walleye, northern pike, and smallmouth bass may not be returned to endangered fish habitat if captured in Utah or key portions of Wyoming, and they can be harvested in unlimited numbers in Colorado.

Anti-escapement devices, such as fish screens or curtains and even energy-dissipating “Bass-O-Matic” (Lake Nighthorse) devices (P. Martinez *et al.* 2014; Bark *et al.* 2014) have been installed at the outlet of six small public reservoirs in the UCRB to reduce the numbers of nonnative fishes that may enter habitat occupied by the various native fishes. The screens are monitored annually and have been shown to prevent escapement, often while fisheries transition to compatible species.

Over the past 15 years, nonnative fish management in the UCREFRP and the SJRIP has been adaptive and continually refined. Sustained nonnative fish management (mechanical removal, reservoir screens, incentive harvests, and use of compatible species) will be required to improve habitat for razorback sucker (Fischer 2018).

In the LCRB, the Long-Term Experimental and Management Plan EIS (U.S. Department of the Interior 2016), and the U.S National Park Service (NPS) Comprehensive Fisheries Management Plan (U.S. Department of the Interior 2013) provide criteria for triggering mechanical removal of nonnative fishes and outline nonnative fish management strategies to employ within the Grand Canyon.

The LCR MSCP helps maintain backwater habitats for razorback sucker as predator-free environments (LCR MSCP 2004). Collecting wild larvae, rearing early life-stage razorback sucker in predator-free settings, and eventually repatriating these fish into locations below Lake Mead are key strategies to help mitigate the effects of predation and competition in the LCRB as well as impacts from river regulation. Brown and rainbow trout are being removed from several locations within Grand Canyon and Glen Canyon National Recreation Area. Nonnative fish removal is not conducted within the remainder of the LCRB due to overall feasibility, however, stocking of disconnected backwaters is being implemented to provide refuge habitats free of nonnative fishes and their detrimental effects on razorback sucker.

Table 3. Summary of nonnative removal in each subbasin

Subbasin	Species Targeted for Removal	Species Removed if Encountered
Green	smallmouth bass, walleye, northern pike	bluegill, black crappie, largemouth bass, yellow perch, tiger muskie, wiper, white crappie, white sucker, burbot, grass carp
Colorado	smallmouth bass, walleye, northern pike	bluegill, black crappie, largemouth bass, yellow perch, tiger muskie, wiper, white crappie, white sucker, burbot, grass carp
San Juan	channel catfish, common carp	All nonnative species
Lake Powell	None	None
Grand Canyon	brown trout, rainbow trout	None
Lake Mead	None	None
Lake Mohave	None	None
Lake Havasu	None	None
Colo. River below Parker Dam	None	None

4.2.4 Research/Monitoring

The programs conduct research and monitoring to generate information on abundance, reproduction, growth, and survival of endangered fish in the wild. Data management systems serve as repositories and analytical tools for the collected information. Data are used to evaluate and adjust management actions and recovery strategies through adaptive management.

In the Green River and upper Colorado River system, UCREFRP estimates adult abundance and survival rates of stocked fish based on data collected during Colorado pikeminnow sampling (Projects 127 and 128), nonnative fish removal passes and location-based monitoring (e.g. Project 163). Presence and density of larval fish are annually documented (Projects 160 and 163). Effectiveness of floodplain wetland management and nonnative removal efforts are studied and documented in Habitat Restoration and Nonnative Fish program elements respectfully. All projects have annual reports and final reports posted on the program's website (www.coloradoriverrecovery.org).

In the San Juan River, the SJRIP uses a standardized fish monitoring plan and protocols developed in 2000 and updated in 2006 that describe the sampling design and strategies to be used in monitoring Colorado pikeminnow and razorback sucker and their habitat as part of the entire fish community (San Juan River Basin Recovery Implementation Program 2016). The monitoring program also provides a basis of new information to be used to update management and conservation activities as part of the Program's adaptive management process. Other monitoring documents fish communities and ecosystem response, habitat availability and restoration efforts, and augmentation effectiveness (San Juan River Basin Recovery Implementation Program 2016). SJRIP also monitors the San Juan arm of Lake Powell.

LCR MSCP conducts research on razorback sucker and its habitats to (1) inform selection and application of conservation techniques, (2) document successful implementation of conservation measures, and (3) develop alternatives to conservation actions that prove ineffective through the Adaptive Management Program (AMP). This helps researchers quantify existing knowledge, identify data gaps, and design and implement species research to fill these data gaps. Conceptual ecological models (CEMs) have been developed for razorback sucker to assist in further identifying these data gaps and help to prioritize and redefine research topics (Lower Colorado River Multi-species Conservation Program 2018).

To support monitoring efforts, all stocked fish are implanted with a passive integrated transponder (PIT) tag that allows each fish to be tracked back to its original stocking or capture event. Remote PIT-tag antennas are distributed throughout the Colorado River basin and routinely detect PIT-tagged razorback sucker. The data are stored and analyzed with all other monitoring data in comprehensive databases managed by the programs.

4.2.5 Augmentation

Hatchery broodstocks and refuge populations of razorback sucker are maintained in various federal and state facilities. Hatchery-produced razorback sucker are being stocked routinely in the UCRB and LCRB. In the LCRB, wild-produced Lake Mohave larvae are collected annually

and are subsequently reared in hatcheries or other protected habitats and repatriated at adult sizes to prevent predation of juvenile fish. The distribution of adult fish from hatchery-raised or collected wild-produced larvae are both considered stocking and augmentation efforts. All fish are stocked at average lengths of 300 mm or more.

The UCREFRP has two facilities dedicated to the production of razorback sucker that each produce and distribute 6,000 razorback sucker averaging 350 mm or greater. The Grand Junction Endangered Fish Facility in Grand Junction, Colorado stocks razorback sucker in the Colorado and Gunnison Rivers and the Ouray National Fish Hatchery in Vernal, Utah stocks razorback sucker into the Green River.

The SJRIP stocks 11,400 razorback sucker annually. Southwestern Native Aquatic Resources and Recovery Center (SNARRC) maintains a captive broodstock population large enough to produce razorback sucker for annual stocking, which are then grown at Navajo Agricultural Products Industry (NAPI) ponds in New Mexico and Horsethief Canyon Native Fish Facility (HCNFF) in Grand Junction, Colorado. A broodstock of 1,176 adult fish of Lake Mohave origin is currently being maintained and managed as identified in SNARRC's RBS Genetics Management and Captive Propagation Plan (2004).

The LCR MSCP Fish Augmentation Program has committed to stocking 660,000 subadult razorback sucker into the Colorado River system over a 50-year term. Between 2005 and 2017, 180,727 were stocked into Reaches 3-5 (Lower Colorado River Multi-species Conservation Program 2018). The broodstock for this effort was developed from larvae collected from Lake Mohave and reared at the Willow Beach National Fish Hatchery in Arizona and the Lake Mead Fish Hatchery in Nevada. Additional fish rearing capacity is available at the Achii Hanyo Native Fish Rearing Facility (Arizona), the Overton Wildlife Management Area (Nevada), and the Bubbling Ponds Fish Hatchery (Arizona) all of which have varying production goals. A second broodstock is maintained at SNARRC (Lower Colorado River Multi-species Conservation Program 2018).

5 CURRENT RESOURCE AND SPECIES' CONDITION

In this section, current condition was evaluated for eight populations, four in each of the upper and lower basins (Figure 10). The four upper basin populations include the Green River subbasin, the Colorado River subbasin, the San Juan River subbasin and Lake Powell. Lower basin populations include Lake Mead (including the Grand Canyon), Lake Mohave, the Colorado River between Davis and Parker dams (Lake Havasu) and the Colorado River below Parker dam. Stocking efforts continue in other areas, including the Verde River, but survival is low, making these populations difficult to assess.

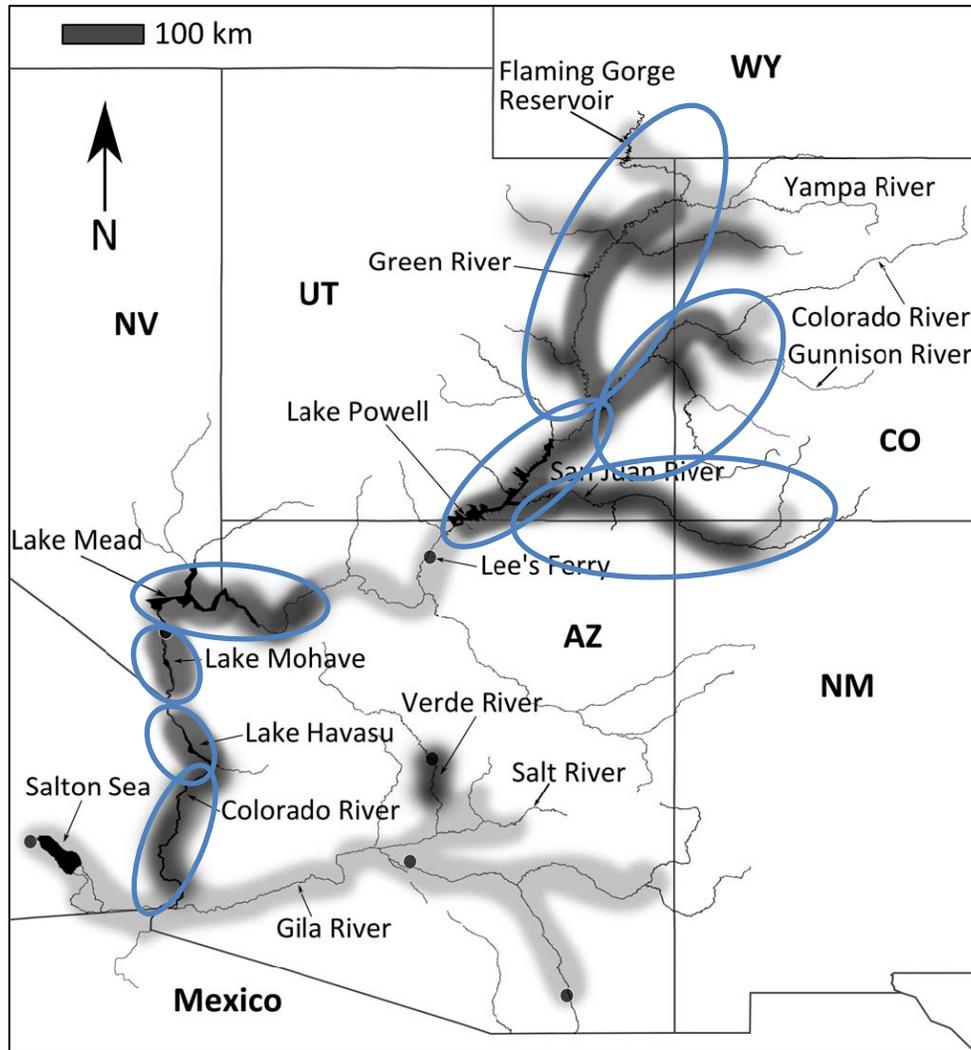


Figure 10. Historical (light gray highlight) and current (dark gray highlight) distribution of the razorback sucker in the Colorado River basin with assessed populations circled (blue).

For each population, we evaluated each of the physical species needs and the demographic response to those needs. We used four condition categories for each species need: high, medium, low or extirpated condition representing a continuum from high (best) to extirpated (worst) condition. Definitions of species needs in each category were developed to provide consistency (Table 4 and Table 5) during assessment of current and future conditions.

Table 4. Condition category table for physical needs of razorback sucker. Each cell below defines the condition under which a category is given for each need.

Physical Needs						
Complex Habitat		Water quality/Temperature	Variable flow (lotic only)	Adequate food	Range & connectivity	
Habitat	Nonnative presence in habitat					
High	Spawning habitat is available throughout the system in close proximity to appropriate larval habitat. Nursery areas are present throughout the system, and accessible to larvae. Cover is available to provide protection in the form of turbidity and/or vegetation. Adult habitat present including open stretches of water, deep pools, low-gradient runs and long-lengths of open river in lotic systems.	Nonnative predators and competitors are rare.	Water temperatures within thermal preferences (between 15 - 25 C) and follow a natural pattern of being lower during spring runoff and warming during summer months. Chronic water quality impairments are absent.	Variation in flow releases or weather patterns provide inter- and intra-annual variability. Natural or regulated flows provide seasonally high flows (e.g., peak discharge from melting mountain snow), promote regular inundation of floodplain depressions and side-channels when larvae are present, sediment sorting to clean spawning beds and the formation of deep pools and side channels, base flows are sufficient throughout the summer.	High productivity occurring throughout the system, larvae have access to warm, food rich environments in most years immediately following emergence.	No impediments or barriers to migration, allowing adults to migrate between river systems and far up rivers and tributaries during the spawning season.
Medium	Spawning habitat is available. Nursery areas are present and accessible to a significant proportion of larvae. Cover is available to provide protection in the form of turbidity and/or vegetation. Presence of adult habitat throughout the system.	Nonnative competition is present, but nonnative predators are uncommon or controlled.	Temperatures follow seasonal patterns, coupled with some depression from dam releases (some periods between 10-15 C during growing season). Chronic water quality concerns such as mercury or selenium or emerging contaminants are present, but not considered a major factor influencing population size or health. Growth and reproduction rates are not impeded.	Natural and regulated flows provide some of the benefits of natural seasonal fluctuations, including periodic connection of some floodplain environments in most years when larvae are present; moderate amounts of sediment sorting and channel complexity occur annually. Some flow variation occurs year to year.	Moderate productivity or impaired water quality that limits the abundance of food items during the larval, juvenile, and/or adult stage.	Barriers are present, but conditions are sufficient in the limited area to provide adequate habitat/conditions for all life stages. Movement is limited between populations.
Low	Spawning habitat is available. Nursery habitats exist in the system but are not available to most larvae. The population is restricted to river reaches and/or lentic habitats that are usually disconnected from seasonally inundated floodplains or coves, and primary cover available is turbidity. Presence of adult habitat throughout the system, but channelization reducing depth and increasing velocities of pool environment.	Nonnative competitors and predators are common throughout the system.	Consistent temperatures between 10-15 C, sufficient to reduce growth. Mercury, selenium or emerging contaminant loading present in some areas throughout the system, reducing reproductive success in those locations.	Regulated flows provide adequate volume to the system, seasonal pattern is generally maintained, but is consistent from year to year. Base flows are present, but low, supporting development of nonnative populations.	Reductions in productivity sufficient to reduce body condition of fish.	Barriers restrict migration sufficiently to form an isolated population restricted to an area too small to support completion of all life stages, possibly preventing access to historic spawning bars or appropriate juvenile habitat.
Extirpated	Spawning habitat compromised by siltation and nursery habitats are infrequent or inaccessible. Slow velocity habitat for adults removed through channel narrowing and simplification, or inaccessible because of lack of connection. Routine low-flow conditions reduce habitat available to adults.	All habitat dominated by nonnative predation and/or competition.	Temperatures consistently depressed below 10 C throughout the year, which precludes development and survival of early life-stages. High levels of water quality contaminants (e.g. heavy metals, emerging contaminants or spills) creating toxic conditions.	Highly regulated flows disconnect the floodplain from the main channel and create a simplified, ditch-like channel morphology reinforced by root masses of invasive trees and shrubs (e.g., Russian olive and tamarisk). Variable flows are rare, if present, supporting growth of nonnative fish populations.	Severe reduction in productivity from reduced temperatures, increased siltation or impaired water quality resulting in reduced survival of one or more life stage.	Upstream and downstream barriers to migration preclude access to suitable habitat(s) to meet larval, juvenile, or adult requirements, which could include floodplain wetlands and backwaters or historic spawning bars. In some cases, the barrier could be a lack of sufficient flows to connect floodplain environments.

Table 5. Condition category table for razorback sucker demographics. Each cell below defines the condition under which a category is given for each need.

	Demographics					
	Adult population size (wild + stocked fish)	Spawning and larval presence	Recruitment	Dependence on stocking	Genetic integrity	Population stability (wild recruited adults)
High	Population is estimated at >5800 as outlined in 2002 recovery goals.	Spawning occurs annually at multiple spawning locations adjacent to appropriate larval habitat. Large cohorts of larvae are produced at multiple spawning sites on an annual basis.	Greater than 75% of juvenile year classes are present (3 of every four years show recruitment) OR Documented wild fish are abundant	Wild populations do not require supplemental stocking, stocking has ceased.	Genetic diversity is high, relatedness values are low, a high percentage of adults participate in reproduction annually and hybridization is low. N_e of 1000 indicating a level of maximum genetic variation.	Population is self-sustaining without stocking. Recruitment is occurring across many generations. OR Average λ^3 equal to or greater than 1 over many years, if measured.
Medium	Population estimates are feasible with sufficient recaptures. Estimates are less than 5800 per population but greater than 500 adults.	Spawning occurs annually at multiple spawning locations. Larval presence documented throughout the system annually, in varying density levels.	40-75% of juvenile year classes are present OR Documented wild fish are common	Stocking present to compensate for a small adult recruitment gap. Wild recruitment occurring, but not at a rate sufficient to offset adult mortality.	Populations show less robust diversity than optimal populations, N_e 500-1000.	Wild population is documented and increasing but must be supplemented with stocked fish occasionally. OR Lambda varies, with values commonly <1, but recurring strong year classes with $\lambda > 1$, if measured
Low	Population estimates are feasible with sufficient recaptures to calculate an estimate but the estimate is low (~500 adults or less)	Low numbers of adult spawners and/or unfavorable environmental conditions (e.g. low temperature or contaminant presence) limits egg production, or larval survival. Larval presence documented at some locations, in low densities.	25% of year classes are present OR Documented wild fish are uncommon OR Untagged fish are found in rates higher than can be attributed to tag loss (10-25% untagged fish)*	Recent stocking is the primary source of individuals in the population, but stocked fish routinely survive (post-first year survival is high >65%).	Pronounced reduction in diversity and increase in relatedness, effects not managed through stocking. N_e of 50-500, sufficient to prevent inbreeding depression, but risks long-term genetic drift.	Wild adults are documented, but at levels too low to determine population trends. OR Wild population trends negative, natural recruitment not occurring at a level to offset adult mortality, must be stocked regularly. OR Lambda almost always <1, if measured.
Extirpated	Individuals in population are too few to support population estimates.	Larval presence is not documented in the population.	Juveniles are rare, captures are inconsistent and/or Untagged adults are present at levels that could be attributed to tag loss (<10%)*	Stocking is needed to maintain species presence; high mortality of all age classes results in no species presence absent stocking efforts (e.g. Verde River)	Bottlenecks occurring in genetic variation because of high relatedness or high hybridization rates. Effects not managed through stocking efforts. N_e of 50 or less resulting in inbreeding depressions.	No wild adults have been documented and wild populations are assumed extirpated OR Wild populations have strongly negative growth rates, likely to result in extirpation. Lambda <1 for many sequential years, if measured.

*A rising number of untagged adults in a system may provide the first indicator that additional studies should be conducted to assess recruitment. Studies using similar species indicate that tag loss is <1% when adults are tagged (Ward and David 2006; Hooley-Underwood *et al.* 2017) and that rates of tag loss can be higher in small juvenile fish (12.5-30%) (Ward *et al.* 2015).

³ The intrinsic rate of population growth.

5.1 Upper Colorado River Basin Resource Conditions

5.1.1 Complex Lotic and/or Lentic Habitat (affected by presence of nonnative fish)

Depending on life stage and location, the razorback sucker uses the suite of available habitats in reservoirs, main channels, backwaters, and floodplain wetlands. Complex habitats including seasonally-connected backwaters, floodplains, and low-velocity slackwaters have diminished due to water development and anthropogenic activities over the last century. However, ample spawning and adult habitat are available throughout the upper basin.

In the Green River, multiple spawning bars are present and commonly used on an annual basis from the Yampa confluence downstream to Millard Canyon. Anecdotal evidence and detections on remote PIT antennas suggest that spawning in tributaries is likely widespread (e.g., Yampa, White, Price, San Rafael). The largest concentration of razorback sucker in the UCRB exists in low-gradient, flat-water reaches of the middle Green River between the Yampa River confluence (RM 570) and Sand Wash (RKM 345.6), including the lower few miles of the Duchesne River, and a recent expansion into the White River (Modde and Wick ; Tyus 1987; Tyus and Karp 1990a; Muth 1995; Muth *et al.* 1998; Muth *et al.* 2000; Bestgen *et al.* 2011; Bestgen *et al.* 2012; Webber *et al.* 2013; STReAMS 2016). This reach also contains the largest expanse of floodplain habitat and nursery habitat in the UCRB (Irving and Burdick 1995; Muth *et al.* 2000). The UCREFRP is currently working to expand access to habitat through both habitat improvement and flow recommendations. One of the most promising tools is the development and management of floodplain wetlands to provide predator-free environments and promote juvenile survival. In the spring, larval monitoring occurs in the river channel. Once larvae are present, flows are increased to increase floodplain connections, allowing the larvae to access the previously disconnected floodplain. The flow is screened to exclude large-bodied predators, but many species of larvae enter the wetland simultaneously. Water quality and quantity is monitored throughout the summer and supplemental water is added if necessary. Each fall, the wetlands are drained, returning native fish to the river and removing any nonnatives present.



Figure 11. Examples of complex habitat including floodplain habitat along the Green River (left) and Colorado River arm of Lake Powell (right) (images from Google Earth).

In the upper Colorado River subbasin, many studies point to the Grand Valley ('15' and '18 mile reaches' of the Colorado River⁴) as important spawning reaches for razorback sucker, as evidenced by ripe fish that are frequently found. The reaches contain numerous cobble bars, complex habitat and readily accessible off-channel ponds (e.g. Walter Walker SWA on the Colorado and the Escalante SWA on the Gunnison). Unfortunately, off-channel ponds are also often filled with large-bodied nonnative predators, making them less conducive for razorback sucker recruitment. In the Gunnison River, capture of ripe females in 2013, 2015 and 2017 indicate that spawning in that system may have occurred near Delta. Extensive cobble bars exist between Hartland Diversion Dam and Escalante SWA, providing spawning grounds upstream of the largest remaining piece of floodplain habitat in the Gunnison basin. Lower reaches of the Colorado River (between Moab and Lake Powell) provide instream habitats like backwaters, embayments, and flooded wash mouths, but which may be compromised by nonnative predators. The State of Utah is currently working to develop a floodplain wetland along the Colorado River near Moab to serve as predator free habitat for larval-juvenile razorback sucker. Adequate adult habitat exists, including deep pools, low-gradient runs and long-lengths of open river throughout the upper Colorado River subbasin.

In the San Juan River, cobble and gravel areas are present throughout the system, though barriers make some areas difficult to access. Currently, backwaters and complex habitats are declining and are low in abundance (Bliesner and Lamarra 2007; Bliesner *et al.* 2008; V. A. Lamarra and Lamarra 2013), but have been shown to increase during higher flow years (V. A. Lamarra and Lamarra 2018). Razorback Sucker spawning has been documented throughout the system with higher larval levels present in backwaters and embayments than in low velocity areas in the river (Farrington *et al.* 2018). Different sections of the river have differing capacities for nursery habitat to form; high discharges maximize formation of nursery habitats (V. A. Lamarra and Lamarra 2018). Side-channels provide seasonal habitat and are actively being restored by the SJRIP. Adequate adult habitat such as deep pools exist throughout the system. Several tributaries, including the Animas River and McElmo Creek in Utah are commonly used by native fish including razorback sucker, showing an increase in use of available habitat (STReaMS 2016, Schleicher 2016).

With the construction of Glen Canyon Dam and the creation of Lake Powell, vast expanses of inflow and lentic habitats were created that resemble historic floodplain and wetland habitat. Lake Powell inflow areas provide habitat for all life stages of razorback sucker, including shallow shorelines for spawning, cover for juvenile fish in inflow areas and deep pools for adults. Recent research documented razorback sucker use of the Colorado River and San Juan River arms of Lake Powell (Francis *et al.* 2013, 2015; USFWS unpublished data). Typically, inflow areas show higher turbidity than reservoir basins year-round, providing protection from nonnative predators (Albrecht *et al.* 2017). Substrate complexity that can be used for spawning and feeding is often found within these inflow areas. Large wood and vegetation transported from the river channel also provides unique, much needed structure at inflow areas. Other areas of the lake have not been studied; use by razorback sucker is unknown.

⁴ The 15-Mile Reach is a river reach that extends from the confluence of the Gunnison River upstream 15 miles to the Grand Valley Irrigation Company Diversion Dam near Palisade, Colorado. The '18-Mile Reach' begins downstream of the Gunnison River confluence, flowing for 18 miles, still in the Grand Valley.

5.1.1.1 Presence of nonnative fish

In the UCRB, smallmouth bass, walleye, channel catfish, and northern pike are predatory nonnative fishes of greatest concern. Northern pike and smallmouth bass are established with high levels of recruitment occurring in certain reaches of the upper Colorado River basin, including the Yampa and Green rivers. Largemouth bass and walleye are primarily emigrants from reservoirs, with no known records of recruitment in riverine portions of the upper Colorado River System. Channel catfish occur throughout the UCRB, but are not considered piscivorous until they reach large adult sizes. Channel catfish may be problematic in the San Juan River.

The Green River and its tributaries support high densities of nonnative fishes that commonly prey on various sizes and life stages of razorback sucker. Three species, smallmouth bass, northern pike and walleye, are highly predaceous and can collectively eliminate or severely deplete entire year classes of razorback sucker. Smallmouth bass are established in the Yampa and Green Rivers and are actively removed by the UCREFRP. Smallmouth bass were rare in Yampa Canyon in 1997, but increased to 18% of the adult fish composition by 2004, concurrent with a decline in native fish composition (Modde and Haines 2005). In response to increasing nonnative fishes throughout the upper basin, the UCREFRP developed a rigorous nonnative fish management program targeting smallmouth bass, walleye and northern pike. Between 2013 and 2016, almost 50,000 smallmouth bass were removed from the Yampa River and an additional 43,000 were removed from the Green River during population monitoring and specific removal efforts (STReaMS 2016). High catch rates of smallmouth bass occurred in 2014 and 2015 after a strong year class developed during low-flow conditions in 2013 (U.S. Fish and Wildlife Service 2017). Northern pike have established populations in the Yampa and upper Green rivers, but are limited by warmer temperatures in lower reaches of the Green River. In 2004, over 800 northern pike were removed from the middle Yampa River (Hawkins 2004). Catch rates have since declined to just over 100 fish in that reach in 2017, indicating that new gill-netting techniques in backwaters and tributary mouths are decreasing populations (C. T. Smith and Jones 2017). Increasing numbers of walleye have been reported in the Green River since 2007 and in the upper Colorado River since 2010 (Michaud *et al.* 2016). Walleye are present in high-elevation reservoirs of Green River tributaries (e.g., Starvation Reservoir) and in Lake Powell, where they are increasing in abundance. Increasing numbers of gizzard shad and walleye in Cataract Canyon may be the result of upstream expansion of Lake Powell populations (Michaud *et al.* 2016).

After the creation of Lake Powell, introduction of non-native fish occurred quickly, now supporting populations of smallmouth bass, largemouth bass, striped bass, walleye, channel catfish, black crappie *Pomoxis nigromaculatus* and bluegill. Inflow areas commonly have inflow- or wind-driven turbidity and inundated terrestrial vegetation, which may offer protection from nonnative fish predation for larval, juvenile, and adult fish (Albrecht *et al.* 2017).

5.1.2 Suitable water temperature and quality

River temperatures in the immediate vicinity of Flaming Gorge Dam (FGD) on the Green River, Crystal Dam on the Gunnison River and Navajo Dam on the San Juan River are cooler than pre-dam averages due to releases from the reservoirs' hypolimnions (Holden 1999; Muth *et al.* 2000; U.S. Department of Interior 2006; McAda 2003; U.S. Department of the Interior 2012). Unlike at the other two dams, flow releases from FGD are managed for temperature at the confluence of

the Yampa, specifying that the temperatures in the Green and Yampa rivers must be close enough to prevent thermal shock. A temperature-control device installed on Flaming Gorge Dam in 1978 is used to warm downstream releases into the Green River and may allow for upstream expansion of native fishes into Lodore Canyon, Colorado. This warming could have provided more suitable conditions for native fish populations in Lodore and Whirlpool canyons.

In river reaches that are not in close proximity to dams, razorback sucker populations in the UCRB experience seasonal temperature variation similar to historic water temperatures. Water temperatures in the UCRB rarely exceed lethal maxima and predominantly remain within optimal range. Both arms of Lake Powell become warmer slightly later in the year, but they arguably exhibit a more natural temperature regime year-round than Lake Mead (Albrecht *et al.* 2017).

Water quality in the upper Colorado River basin is usually not a concern for razorback sucker. However, considerably more selenium is found in the Colorado River above the Green River confluence than in the Green and San Juan river basins. Selenium remediation has been implemented in the Gunnison River, and sources of selenium have been identified within the Green River (e.g., Stewart Lake) (U.S. Fish and Wildlife Service 2017) the specific effects of which are not currently known. Some evidence exists for negative impacts to reproductive biology of razorback sucker (Hamilton 1998; B. C. Osmundson *et al.* 2000). Fish consumption advisories are in place for mercury concentrations in various species in many upper basin waterbodies, including the Desolation-Gray reach of the Green River, Lake Powell, and Elkhead, Ridgway, Rifle Gap and Navajo reservoirs.

5.1.3 Variable Flow Regime

In general, river regulation in the UCRB has caused reductions in peak flows and increases in base flows when compared to pre-dam averages. This is especially evident in the Green (Figure 12), Gunnison, Colorado, and San Juan rivers. The construction of Flaming Gorge Reservoir in 1962 as well as smaller diversions throughout the Green River basin impacted flows and sediment transport; peak flows were reduced, base flows were modified, and sediment transport was reduced.

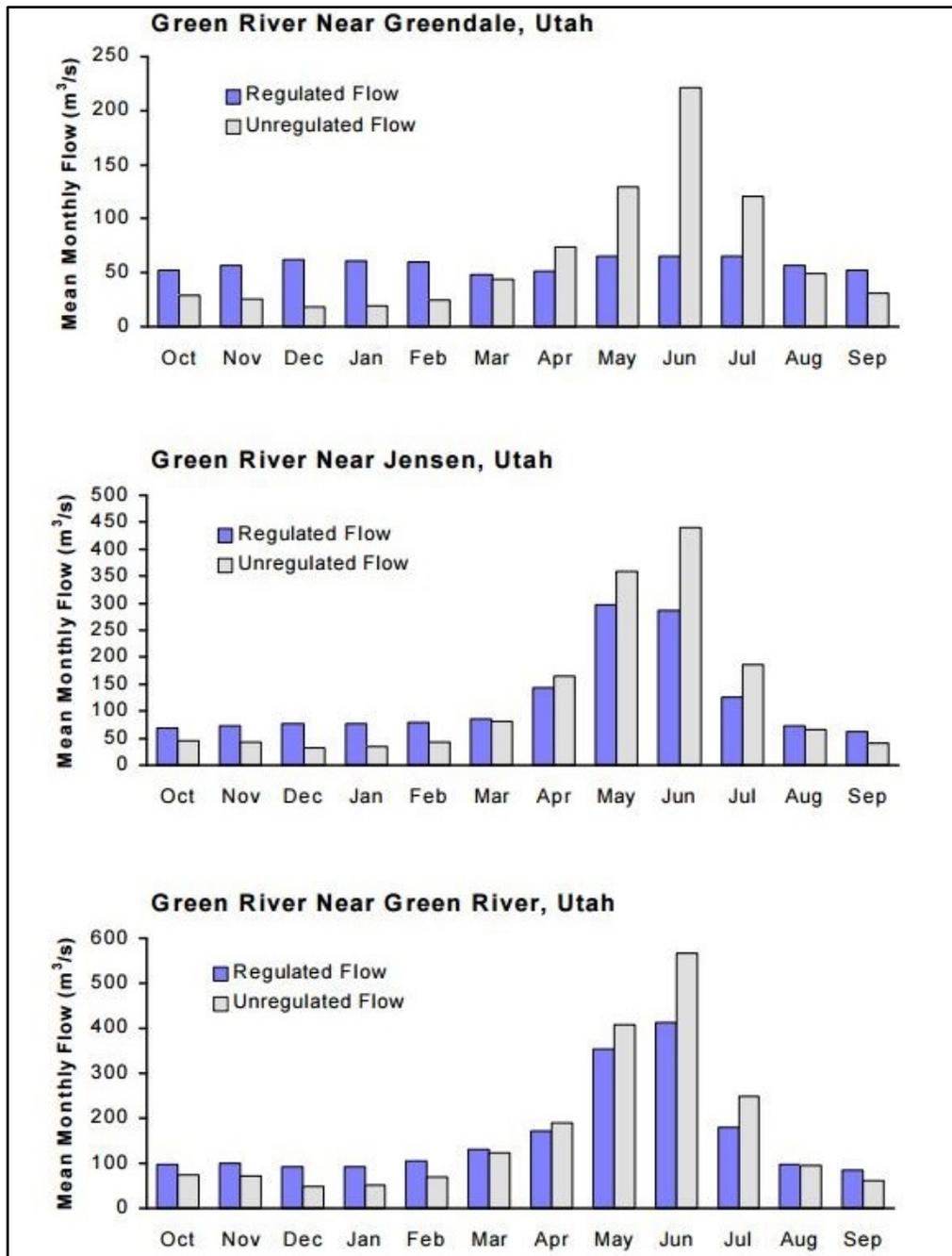


Figure 12. Average monthly flows as recorded at three locations on the Green River from 1963-1996 depicting varying levels of regulation: (top) immediately downstream of Flaming Gorge Dam (i.e., most regulated river reach) at the near Greendale, Utah, gage (Station Number 09234500); (middle) downstream of the confluence with the unregulated Yampa River (i.e., moderately regulated reach) at the Jensen, Utah, gage (Station Number 09261000); (bottom) downstream of additional tributary inputs (White, Duchesne, Price rivers) (i.e., least regulated reach) at Green River, Utah (Station Number 09315000) (reproduced from Muth *et al.* 2000).

High spring flows are required to reconnect backwaters and floodplains, which provide low-velocity nursery habitat for razorback sucker larvae. The UCREFRP has been coordinating with Reclamation to manage spring flows to provide these important floodplain connections on the:

1) Green River since 2006 (Muth *et al.* 2000; U.S. Department of Interior 2006); 2) Colorado River since 1999 (D. B. Osmundson *et al.* 1995; U.S. Fish and Wildlife Service 1999) and 3) Gunnison River since about 2010 (McAda 2003; U.S. Department of the Interior 2012).

A synthesis of larval razorback sucker captures (1992–2009) from the Green River (Bestgen *et al.* 2011) indicated that spring flow management at Flaming Gorge Dam could be better refined by timing floodplain connection releases to coincide with real-time captures of larval razorback sucker. A Larval Trigger Study Plan (LTSP) was developed to test this hypothesis (LaGory *et al.* 2012). Since 2012, LTSP releases have been coordinated with razorback sucker sampling (Figure 13). Current flow recommendations contain: 1) provisions for spring peak flow timing to enhance entrainment of larvae in floodplain wetlands; 2) peak flow magnitude / duration / frequency guidelines for channel maintenance and modification and 3) provisions to vary the base flow period (July - March of each year) by 25-40% above or below target values for each hydrologic category, which provides for intra-annual variability (Muth *et al.* 2000).

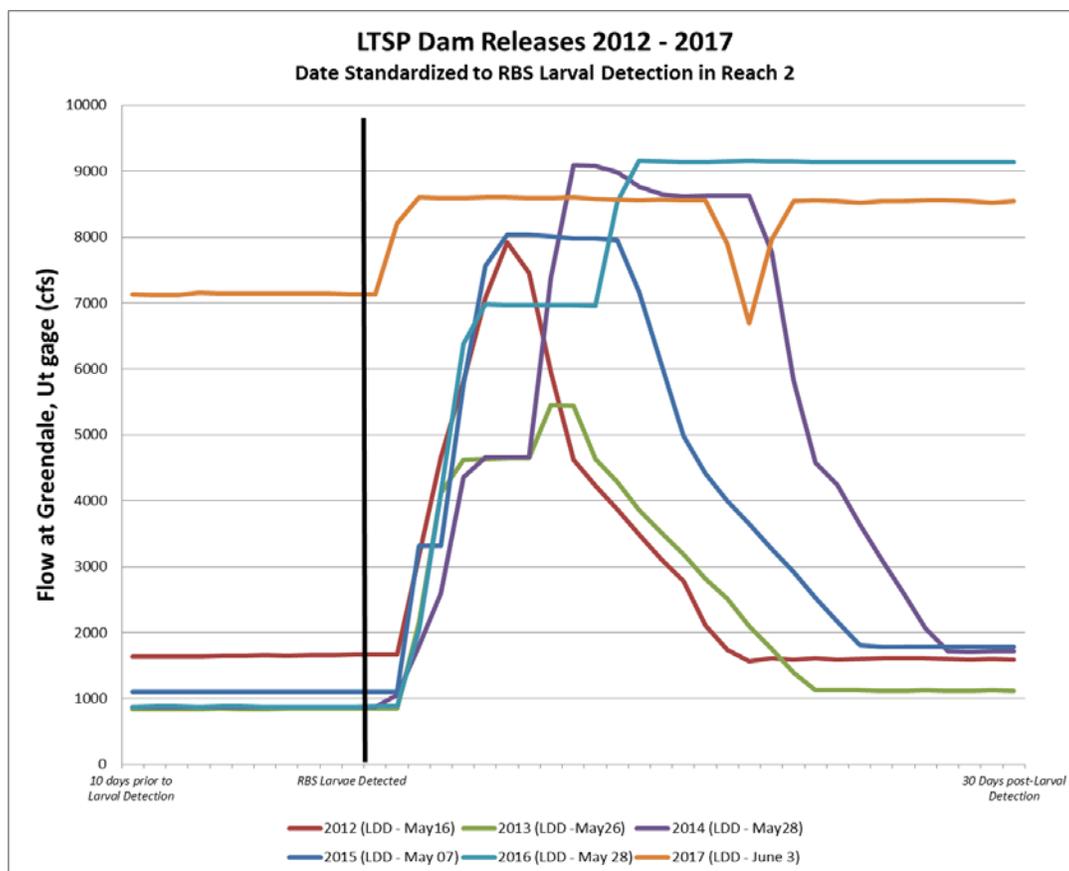


Figure 13. Reclamation’s spring Larval Trigger Study Plan releases from Flaming Gorge Dam, 2012–2017, as measured at the US Geological Survey (USGS) near Greendale, Utah, gage (Station Number 09234500). The chronology of annual hydrographs has been standardized to first larval detection date (LDD). Actual annual LDDs are identified in the legend. Reach 2 is from the confluence with the Yampa River to the confluence with the White River.

The dam releases depicted in Figure 13, coinciding with emergence of larval razorback, have transported these larvae into at least one Green River floodplain study site every year and into multiple floodplain study sites in 2014 and 2015 (Schelly and Breen 2015; Jones *et al.* 2015).

Continued long-term commitment to flow management and LTSP will be necessary to maintain floodplain habitat connectivity that results from this management.

The Gunnison River contributes approximately 40% of the water in the Colorado River at the Colorado/Utah state line (McAda 2003). Water development has reduced the quantity of water in both the Colorado River mainstem as well as in the Gunnison River. Flow recommendations were developed to provide habitat and environmental cues for spawning, and include low velocity habitats for adult staging during runoff, floodplain inundations, in-channel habitat restoration and maintenance and providing base flows to promote growth and survival of young fish during summer, autumn and winter (McAda 2003). In the upper Colorado River mainstem, Coordinated Reservoir Operations (CROS) is an ongoing program implemented by UCREFRP to coordinate bypasses of reservoir inflows to enhance spring flows and improve habitat in the '15-mile reach' which flows through Grand Junction, Colorado upstream of the confluence with the Gunnison River. During the past 26 years, flows have exceeded 'wet' year targets at their desired frequencies, but have fallen short in lower-flow years (Anderson *in prep*, Figure 14). For the Gunnison River, a Programmatic Biological Opinion (PBO) provided consultation on water projects, resulting in a change in operations in the Aspinall Units to provide peak flows in coordination with the peak flow of the North Fork of the Gunnison (U.S. Fish and Wildlife Service 2009a). Operations under the Aspinall PBO are also intended to be beneficial to endangered fish communities in the Colorado River below the confluence of the Gunnison River.

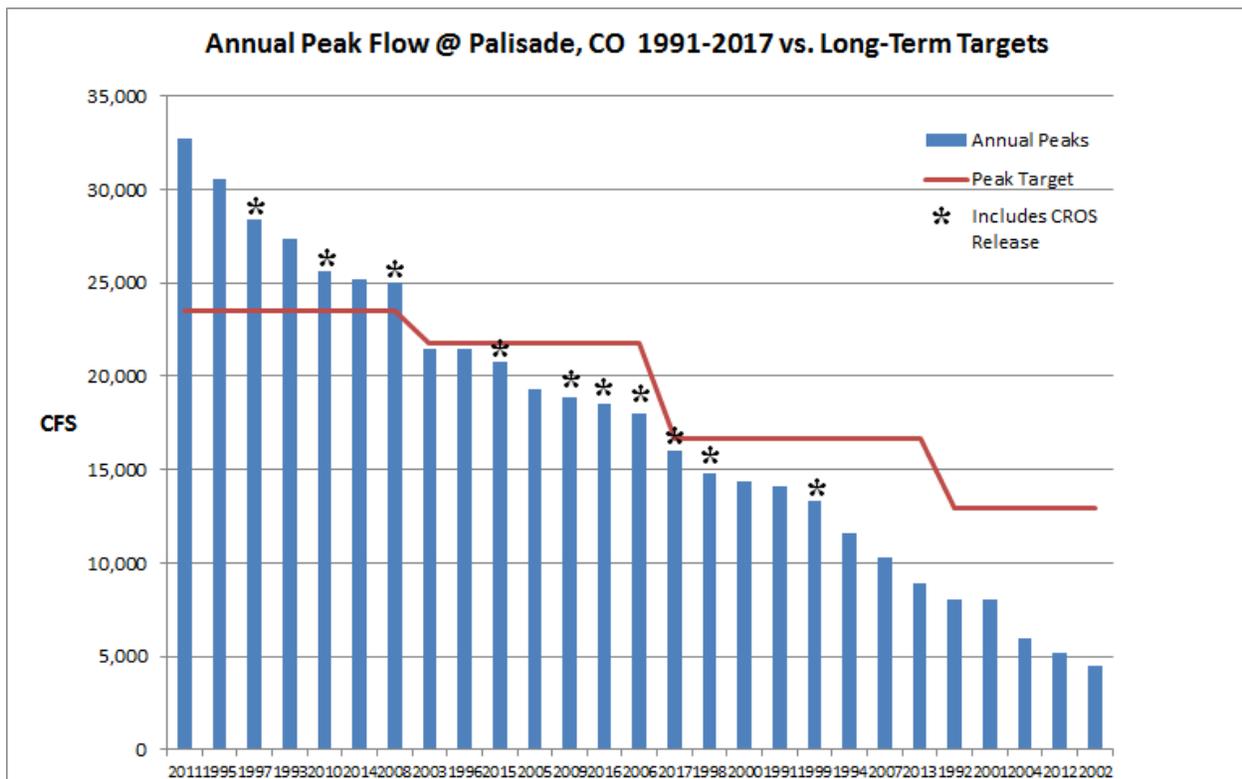


Figure 14. Annual peak flows at the top of the '15-mile reach' including augmented flow from CROS releases documented by flows at the USGS gauge on the Colorado River near Cameo, Colorado (Station No. 09095500). The red line illustrates the recommended frequency of peak flows exceeding particular magnitudes over a 27-year period. Figure from 15-mile Reach Programmatic Biological Opinion review (Anderson, *In prep*).

Navajo Reservoir Dam was constructed on the San Juan River in 1962 just south of the Colorado border in New Mexico to store flows from the San Juan, Los Pinos, and Piedra rivers. The San Juan River is similar to the Green and Colorado Rivers, in that they are large rivers with high spring flows and low base flows with off-peak variation provided by precipitation storm events (Holden 1999). Prior to construction of the Navajo Reservoir Dam, the annual average daily peak flows of the San Juan River were 8,230 cubic feet per second (cfs), which decreased to 2,725 cfs after the dam was implemented (Lamarra and Lamarra 2016). Flow recommendations were developed for operation of Navajo Dam in 1999, which were designed to mimic the natural hydrograph with intra- and inter-annual variability (Holden 1999). Since implementation, flows increased 47% to an annual average daily peak flow of 3,900 cfs (Lamarra and Lamarra 2016, Figure 15). Later studies indicate that the prescribed flows, in combination with establishment of nonnative vegetation, are not mimicking natural conditions as anticipated and are causing diminishment of complex habitats designed to support juvenile growth and maturation of native fish (Bliesner and Lamarra 2007; Bliesner *et al.* 2008; Lamarra and Lamarra 2013). The SJRIP implemented a new decision tree in 2016 to more frequently attain longer duration releases by determining attributes of current flows, developing a monitoring program to evaluate flow hypotheses and developing a structure for finalizing new flow recommendations and operations (San Juan River Basin Recovery Implementation Program 2016).

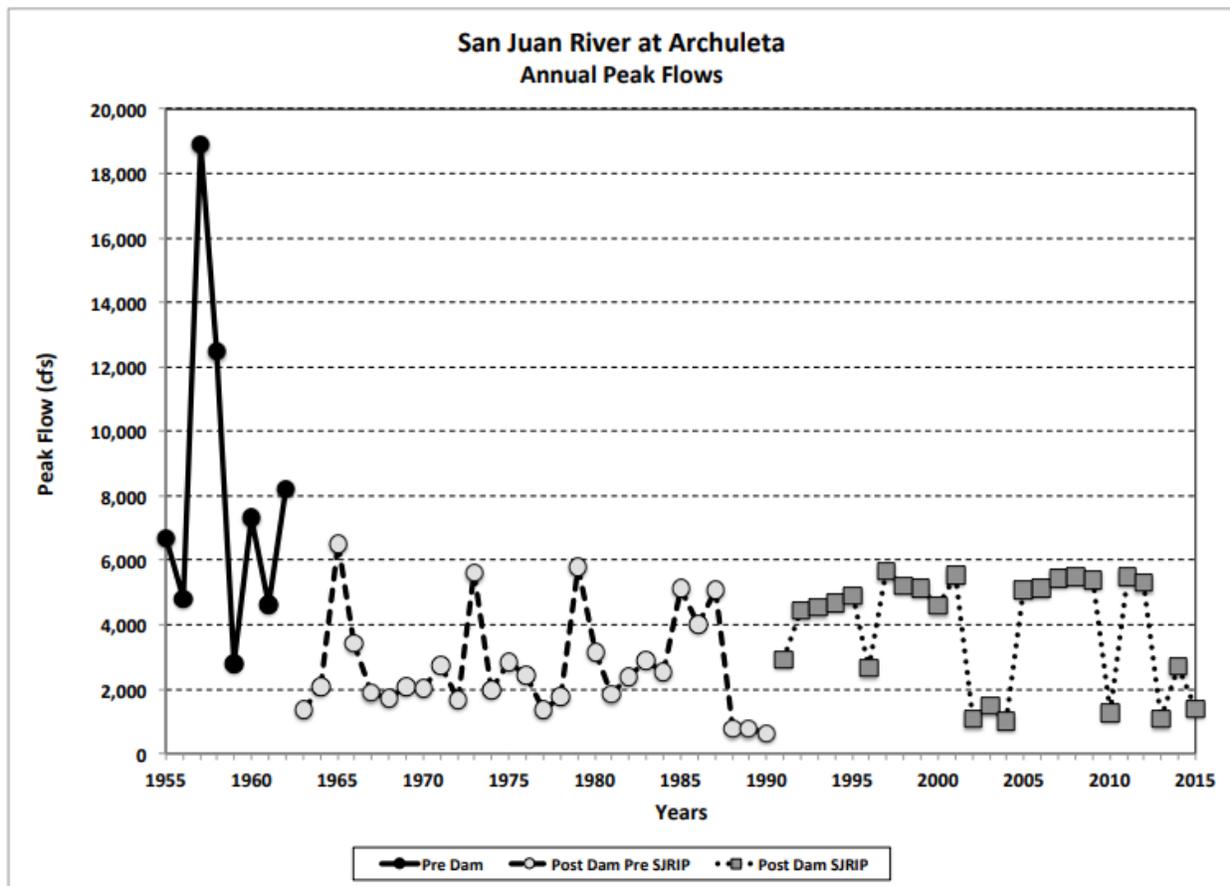


Figure 15. Annual maximum peak daily flows in the San Juan River from USGS gauge at Archuleta, San Juan River (Station No. 09355500), divided into three time periods: Pre-dam (1955-1962, black dots), post-dam, pre-SJRIP (1963-1991, light gray dots), and post-dam, post-SJRIP (1991-2015, gray squares). Figure from Lamarra and Lamarra 2016.

5.1.4 Food Supply

Food supply and availability for razorback sucker in the UCRB is not fully understood or described for all populations. The San Juan River macroinvertebrate community has been described as being of low diversity and high abundance below Navajo Dam (Holden *et al.* 1980; Dubey and Jacobi 1996; Brooks *et al.* 2000) with increased diversity and reduced abundance downstream (Sublette 1977; Holden *et al.* 1980; Brooks *et al.* 2000). Density and diversity of macroinvertebrates are also reduced in the San Juan River compared to the upper Colorado, Yampa, and Green rivers (Holden and Crist 1981; Rader and Ward 1988; Brooks *et al.* 2000; Miller and Lamarra 2006). While macroinvertebrate communities in the Yampa and Green rivers typically display increasing abundance from spring to fall (Holden and Crist 1981), the opposite was described in the San Juan River (Brooks *et al.* 2000). Although the study was not specific to razorback sucker food items, Rader and Ward (1988) found that macroinvertebrate taxa were reduced under regulated flows on the Colorado River downstream of Granby and Shadow Mountain reservoirs, and taxa abundance was higher compared with other regulated streams in the Rocky Mountains. As noted above, connection to floodplain wetlands is essential to provide larvae with protection to survive their first summer. Floodplain wetlands are usually more productive and warmer than main channel habitats during spring and early summer, which allows entrained larvae to grow substantially (Bestgen *et al.* 2011; LaGory *et al.* 2012).

5.1.5 Range and Connectivity

Razorback sucker exhibit movement across hundreds of miles among UCRB riverine and reservoir habitats. While limited by major barriers such as Glen Canyon Dam and the waterfall on the San Juan arm of Lake Powell, this degree of movement is likely similar to historical conditions. Fish passage structures have been built across all remaining diversion structures in the Green and Colorado river subbasins. Work is continuing on the San Juan, but restrictions to movement remain. From 1981-2015, nearly 1,350 razorback sucker demonstrated movement from one river to another, while the majority of the almost 400,000 fish PIT tagged fish encountered in the system moved less than 10 miles (Figure 16). Many of these movements are tributary to mainstem and vice versa, but some were of a larger scale. For example, one razorback sucker stocked into the San Juan River was detected in the Green River two years later; three other razorback sucker stocked in the San Juan River were detected in the Colorado River near the Colorado/Utah state line (Francis *et al.* 2015; Durst and Francis 2016). Thus, connectivity between the San Juan River and Colorado River mainstem and tributaries exists to some degree through Lake Powell. This information suggests the potential for connectivity and a metapopulation framework for razorback sucker within the UCRB. The only large-scale barrier remaining in the UCRB is the San Juan waterfall, a natural barrier that is compromised when Lake Powell is full, which is becoming less common as Lake Powell levels drop. Glen Canyon Dam does still separate the UCRB from the LCRB, preventing inter-basin movement.

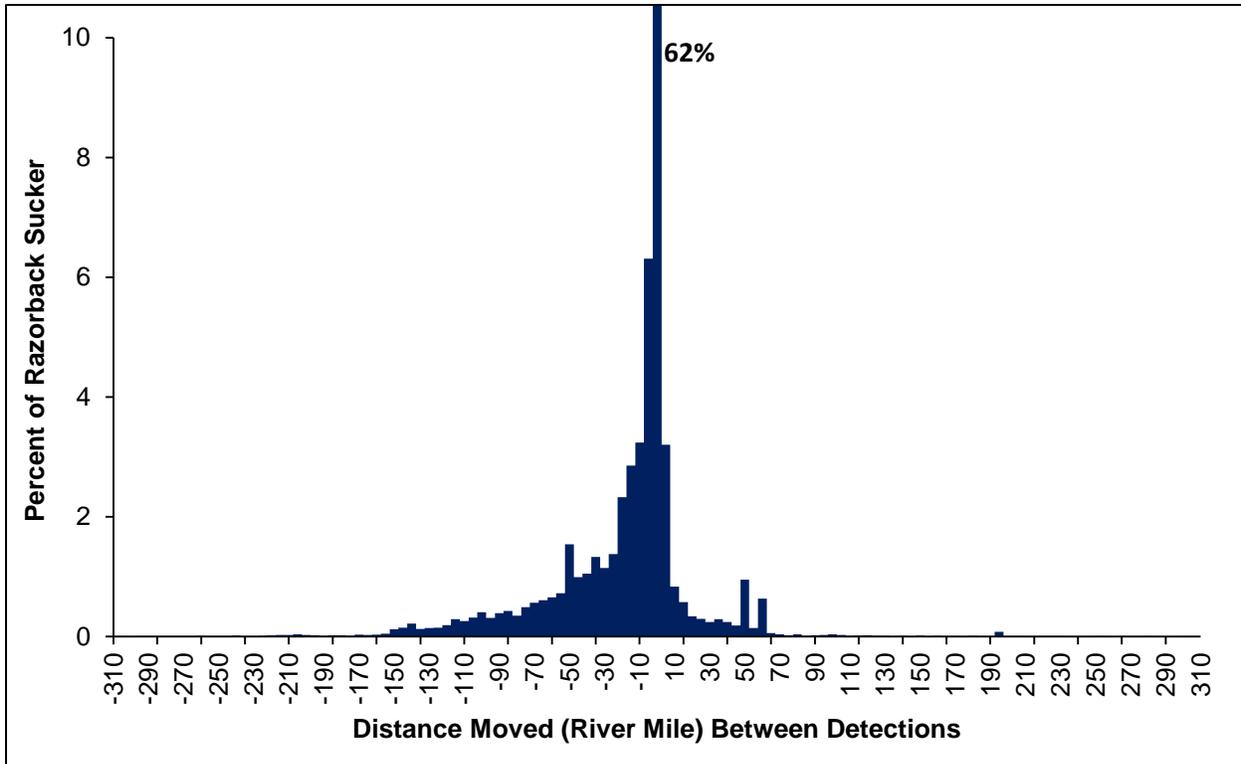


Figure 16. Movement of razorback sucker between capture and resighting from 1981 to 2015 displayed as a proportion of passive integrated transponder (PIT)-tagged fish (from STReaMS 2016).

5.1.6 Summary of Upper Basin Resource Conditions

Table 6. Summary of upper basin physical resources current condition for razorback sucker (high condition is represented by green, medium condition by yellow, low condition by orange and extirpated condition by red).
The gray box around Lake Powell is meant to indicate a lack of scientific data in comparison with other upper basin populations.

Physical Needs						
Complex lotic/lentic habitat		Water quality/Temperature	Variable flow (lotic only)	Adequate food	Range & connectivity	
Habitat	Nonnative presence in habitat					
Green River Subbasin (plus inflow areas of Lake Powell)	<ul style="list-style-type: none"> Multiple spawning bars are present and commonly used in Green River mainstem and tributaries. Floodplain wetlands are available for use as nursery habitats in the Middle Green River where high levels of spawning activity occurs Habitat for juveniles is present in the lower Green River in the form of backwaters, embayments and wash mouths, but are frequently compromised by nonnative predators UCREFRP is actively trying to manage wetlands to provide sheltered, larval rearing habitat with varying results based on environmental conditions Adequate adult habitat exists; including deep pools, low-gradient runs and long-lengths of open river, and adults have access to Lake Powell 	<ul style="list-style-type: none"> Northern pike are actively recruiting and abundant in the Yampa, common in the Upper Green and present in the mainstem downstream and in other tributaries. Smallmouth bass are common above Green River, UT, with spawning and successfully recruiting populations Walleye have become more common since 2010 Channel catfish and small nonnative cyprinids are abundant in low velocity areas 	<ul style="list-style-type: none"> Water quality is thought to be sufficient to support all life stages Water temperatures are artificially colder directly below FGD, but typically warm quickly; flows are managed to meet temperature criteria at the confluence with the Yampa River The effects of high selenium concentrations remain unknown, but are currently under investigation Floodplain wetlands may be more prone to contamination from selenium and mercury and are critical to recruitment in the basin Other water quality concerns and their effects on reproduction have not been evaluated (i.e. other heavy metals, endocrine disruptors, hydrocarbons) 	<ul style="list-style-type: none"> Peak flows have been reduced since the construction of FGD, coupled with modified base flows Flow recommendations provide intra- and inter-annual flow variability to meet a range of razorback sucker life history-specific needs New flow recommendations are in progress for the White River. The Yampa River is largely unregulated and often provides a significant volume of the spring peak flow and intra-annual variability due to precipitation events outside the spring peak period 	<ul style="list-style-type: none"> Adequate food is present for adults Floodplain wetlands provide significantly greater food and temperature resources to larval RBS than the main channel environment, but nonnative predators and competitors are frequently abundant 	<ul style="list-style-type: none"> Range is seasonally limited by cold temperatures for a short distance below Flaming Gorge Dam Fish migrate throughout the upper basin system including the Yampa and White Rivers (upstream to Taylor Draw Dam) and through the Colorado, Dolores, Gunnison and San Juan rivers and Lake Powell A fish passage was recently constructed at the Tusher Wash Diversion, making the entire Green River subbasin accessible to endangered fish at all times of the year
Colorado River Subbasin (plus inflow areas of Lake Powell)	<ul style="list-style-type: none"> Spawning bars are present in the mainstem Colorado as well as tributaries like the Dolores and Gunnison UCREFRP has developed gravel pits along the river to provide age-1 and juvenile habitat, but many are deep, cut off from the river, and full of nonnative fishes One wetland is currently in development and will be managed similarly to those in the Green Lower reaches provide instream habitats like backwaters, embayments, and flooded wash mouths, which may be compromised by nonnative predators Adequate adult habitat exists; including deep pools, low-gradient runs and long-lengths of open river and adults have access to Lake Powell 	<ul style="list-style-type: none"> Northern pike are present in floodplain gravel pits and are actively removed, but rare in the river itself Smallmouth bass are widely distributed, but at lower densities than in the Green Walleye catches have increased in recent years, with large numbers captured 2013-2015 Channel catfish and small nonnative cyprinids are abundant in low velocity areas 	<ul style="list-style-type: none"> Water quality is thought to be sufficient to support all life stages The effects of high selenium concentrations on reproductive success remain unknown, but are currently under investigation Other water quality concerns have not been evaluated (i.e. mercury, other heavy metals, endocrine disruptors, hydrocarbons) Temperatures in the Colorado seem well within tolerance levels, temperatures in the Gunnison are depressed because of dams 	<ul style="list-style-type: none"> Peak flows have been reduced and base flows modified following the completion of multiple upstream dams. Active management prioritizes water through the '15-mile Reach' Flow recommendations seek peak flow magnitude/duration/frequency guidelines for channel maintenance and provisions for minimum and base flow; targets have been met in most years (2012 Aspinall ROD and CROS) 	<ul style="list-style-type: none"> Adequate food is present for adults Floodplain wetlands provide significantly greater food and temperature resources to larval RBS than the main channel environment, but nonnative predators and competitors are frequently abundant Uncertainty remains as to whether or not a lack of appropriate food items is preventing recruitment in the river 	<ul style="list-style-type: none"> Range is seasonally limited by cold temperatures for a short distance below Aspinall Units Fish migrate throughout the system including the Dolores and Gunnison rivers and through the Green and San Juan rivers and Lake Powell Construction of fish passages have reconnected habitats that were previously blocked by diversion structures. No permanent barriers remain in razorback sucker habitat in the Colorado subbasin.

		Physical Needs					
		Complex lotic/lentic habitat		Water quality/Temperature	Variable flow (lotic only)	Adequate food	Range & connectivity
Habitat	Nonnative presence in habitat						
San Juan River Subbasin (plus inflow areas of Lake Powell)	<ul style="list-style-type: none"> • Spawning areas are present throughout the system in varying conditions • Low abundance of backwaters in the river driven by higher gradient • Side-channels provide seasonal habitat and further restoration work is planned to increase quantity • Adequate adult habitat exists, including deep pools 	<ul style="list-style-type: none"> • Channel catfish are well established, growing to large sizes which are piscivorous, but are not thought to have the same effect as other nonnative predators • Small nonnative cyprinids are abundant in low velocity areas 	<ul style="list-style-type: none"> • Water quality is sufficient to support all life stages • The effects of high selenium and mercury concentrations on reproduction are in dispute, but are currently under investigation • Water temperatures support all life stages, but are artificially depressed below Navajo dam • Other water quality concerns have not been evaluated (i.e. mercury, other heavy metals, endocrine disruptors, hydrocarbons) 	<ul style="list-style-type: none"> • Navajo Dam limits flow variability; reducing peak flows, modifying base flows and rarely allowing high flow events • Dam does provide protection against extreme low flows • In 2016, a new agreement was developed to increase frequency of releases and evaluate elevated baseflows 	<ul style="list-style-type: none"> • Adequate food is present for adults • Uncertainty remains as to whether or not a lack of appropriate food items is preventing recruitment, and is complicated by a heavy nonnative fish presence in all juvenile habitat 	<ul style="list-style-type: none"> • Range is seasonally limited by cold temperatures for a short distance below Navajo Dam • SJR (Piute Farms) waterfall prevents movement of fish between San Juan Arm of Lake Powell and San Juan River, but fish can pass if Lake Powell water levels are high enough • Numerous in-stream barriers persist in both the San Juan and Animas rivers, despite attempts to modify them for fish passage • Few fish present above PNM Weir (RM 166.7) and movement upstream through fish passage is limited 	
Lake Powell (including inflow areas and the lake proper)	<ul style="list-style-type: none"> • Clean talus, cobble and gravel areas used for spawning are present throughout the system • Sufficient turbidity likely exists at the river/lake interface inflow areas, providing cover for fish on both river arms. • Inflow areas could be receiving larvae from the riverine systems and may provide the habitat needed to recruit • Significant numbers of stocked razorback sucker migrate to Lake Powell, potentially indicating high quality adult habitat 	<ul style="list-style-type: none"> • Nonnative predators are common in the lake and managed as sportfish • Small nonnative cyprinids are abundant in low velocity areas 	<ul style="list-style-type: none"> • Water quality is sufficient to support all life stages • Other water quality concerns have not been evaluated (i.e. other heavy metals, endocrine disruptors, hydrocarbons), but are likely comparable to other systems both up and downstream 	<ul style="list-style-type: none"> • Variable flow not applicable in Lake Powell, but annual filling and draining cycles likely create high-quality shelter for larval and juvenile fish during the spring-peak • Certain lake levels expose more near-shore habitat which can be advantageous to razorback sucker 	<ul style="list-style-type: none"> • Abundant food is present in the lake habitat, resulting in high body condition factors 	<ul style="list-style-type: none"> • Fish migrate around the lake without barriers • Fish movement among Lake Powell, the San Juan, and the Green and Colorado subbasins have been documented • The SJR (Piute Farms) waterfall does block connectivity (and nonnative fish intrusion), a phenomenon which could also conceivably occur on the Colorado if lake levels drop far enough 	

5.2 Lower Colorado River Basin Resource Conditions

5.2.1 Complex Lotic and/or Lentic Habitat

With three large mainstem reservoirs (Lakes Mead, Mohave, and Havasu) from Glen Canyon Dam downstream to the Gulf of California, the LCRB contains both lentic and lotic razorback sucker habitat (Figure 17). Spawning grounds are present and commonly used in both Lake Mead and Lake Mohave, in the Colorado River between Davis and Parker dams (Lake Havasu) and in the Colorado River below Parker Dam (Kesner *et al.* 2014; Mohn *et al.* 2017; Kesner *et al.* 2017; L. J. McCall *et al.* 2017). Natural and modified backwaters and floodplain habitat types are available for razorback sucker throughout the LCRB including oxbows, abandoned river channels, secondary channels, and isolated coves in reservoirs (Saiki *et al.* 1980; Valdez *et al.* 2012). Additionally, disconnected backwaters are created and managed by the LCR MSCP as refugia for stocked razorback sucker. Growth rates and body condition of adults in LCRB reservoirs are high, indicating the abiotic features formed by reservoirs can be diverse, and alone may be beneficial to adults of the species. However, with the exception of Lake Mead, recruitment is non-existent or limited by the persistent presence of nonnative fish.



Figure 17. Complex lotic and lentic habitat within the LCRB. The Little Colorado River confluence in the Grand Canyon (left), the Colorado River confluence to Lake Mead (center), and Imperial Ponds and other off-channel features below Parker Dam (right) (from Google Earth).

The Lake Mead population has access to Colorado River in Western Grand Canyon, providing additional diverse habitat. When Lake Powell filled in the mid-1960's, Lake Mead elevations were dramatically decreased, allowing for the establishment of near-shore vegetation. From 2012-2015, water level drawdown associated with drought has allowed terrestrial vegetation to colonize in a downslope direction, which when coupled with annual elevation increases during spring may be providing cover in coves and other habitats that allow for the recruitment occurring there (Mohn *et al.* 2017). The complex vegetation coupled with high levels of turbidity near the inflows makes recruitment successful, especially in the Virgin River/Muddy River inflow and Las Vegas Bay (Mohn *et al.* 2017). Lake Mead has a sizeable nonnative fish presence, currently dominated by gizzard shad, common carp, striped bass, largemouth bass, smallmouth bass, black crappie and bluegill (Mohn *et al.* 2017).

After the creation of Lake Mohave in the 1950's, one of the largest remaining populations of razorback sucker persisted in the reservoir for many years but had declined by the early 1990's (Marsh *et al.* 2003; W. L. Minckley *et al.* 2003). Multiple spawning grounds are visited annually, where razorback sucker clear silt from gravel beds. Unlike Lake Mead, there is little inundated shoreline vegetation, low habitat complexity and low levels of turbidity, potentially limiting cover for juveniles attempting to escape predation. Striped bass are plentiful in the reservoir and are a documented source of juvenile and adult mortality of razorback sucker (Karam and Marsh 2010).

The Lake Havasu population occupies the reach between Davis and Parker dams, including 54 miles of the Colorado River and the entirety of Lake Havasu. Annual spawning congregations are found from Laughlin, Nevada downstream to Needles, California (Kesner *et al.* 2017). Fish have access to a variety of habitats, including fast-flowing waters in the riverine section below Davis Dam, low lying rocky canyon-like shorelines with backwater habitat as well as gently sloping shorelines in the reservoir (Kesner *et al.* 2017). Conditions of cover and turbidity are similar to Lake Mohave and most likely do not provide sufficient cover for larval fish to escape predation by nonnative fish. However, the Bill Williams River inflow to Lake Havasu has similar physicochemical characteristics to those of Lake Mead inflows including vegetative cover and occasional turbidity (Humphrey *et al.* 2014, 2016; Karam *et al.* 2013) but little utilization by stocked bonytail or razorback sucker.

Below Parker Dam miles of lotic and lentic habitat extend to Yuma, Arizona. Both channelized and natural reaches contain a variety of in-channel habitats (sand bars that create side channels and eddies) and natural and reconstructed backwaters that are connected to the lower Colorado River. Conservation actions have been implemented to create isolated backwaters that are representative of historical conditions during low-flow periods (U.S. Department of Interior 2005). Conditions of cover and turbidity are similar to Lake Mohave and most likely do not provide sufficient cover for larval fish to escape predation by nonnative fish.

5.2.2 *Suitable water temperature and quality*

The construction of large mainstem dams has altered water temperatures throughout the LCRB. One example is the Colorado River through the Grand Canyon, which historically experienced diel and seasonal temperature variations from freezing in the winter to near 30 °C in late summer. Before the construction of Glen Canyon Dam, the warmest water temperatures were in July and August (Valdez and Carothers 1998). Because of the hypolimnetic release of water through the dam, water temperatures at Lee's Ferry range from approximately 8 to 14 °C, with the warmest temperatures occurring in October and November (U.S. Geological Survey 2016a). This water warms to over 20 °C as it flows downstream into Lake Mead. Lake Mead water temperatures ranged from 10.4 to 31.2 °C in 2010 in the Temple Basin just downstream of the Colorado River Inflow (CRI) (U.S. Geological Survey 2016b). From Lake Mead, water is released into Lake Mohave where water temperatures ranged from 11.0 to 30.6 °C in 2014 (U.S. Geological Survey 2016b). Similarly, water temperatures downstream of Lake Mohave in Lake Havasu ranged from 12.9 to 28.6 °C in 2014 (Central Arizona Project 2015). Warm releases from Glen Canyon Dam in association with low reservoir levels have been investigated,

providing insight to the possible effects of warming on native and nonnative fishes in the Grand Canyon either from low reservoir levels or use of a temperature control device.

Despite cooler water temperatures, relative lack of nutrients, and much reduced sediment transport, razorback sucker are spawning in the Grand Canyon (Albrecht *et al.* 2014; Kegerries *et al.* 2015), recruiting in Lake Mead (Albrecht *et al.* 2010; Mohn *et al.* 2015), and reproducing in Lake Mohave (Delrose 2012). Razorback sucker appear to be opportunistic and successful at spawning in a variety of water temperatures, but water temperature does play an important role in hatching, growth, and survival of larvae (Marsh 1985; Bozek *et al.* 1990; Bestgen 2008).

Water quality in the LCRB is thought to be sufficient to support all life stages of razorback sucker, but elevated concentrations of selenium are found near Imperial Dam (Engberg 1999). Thus, the same suite of concerns and controversy around the effects of selenium observed in the UCRB apply here as well.

5.2.3 Variable flow regimes

Creating spawning and rearing habitat through higher spring flows and connecting backwater and floodplain habitat types is an important aspect of supporting razorback sucker life history, but it may not be possible given the high degree of river regulation, nonnative fishes and habitat changes in the LCRB. Variable flow is thought to be important in the lotic components of razorback sucker habitat, but not essential in reservoir habitat. Some annual variation in reservoir level is thought to support various life stages, but dramatic increases or decreases in reservoir stage can have deleterious effects, especially during spawning season when eggs may be dried by falling water levels (L. J. McCall *et al.* 2017).

Discharge has been altered through the construction of dams and water development within the LCRB. Flows in the Grand Canyon are largely dependent on dam releases rather than natural runoff events, although monsoonal flooding through major tributaries (e.g. Little Colorado River, Paria River) can produce significant increases in main channel flow. Dam releases and operations have changed at Glen Canyon Dam and throughout the Grand Canyon since the first decades following dam completion, resulting from research conducted by the Glen Canyon Adaptive Management Program. The releases prior to 1991 included large diel fluctuations (nearly 15,000 cfs/day). Flows currently fluctuate with diel hydropeaking operations at Glen Canyon on the order of approximately 5,000 to 8,000 cfs/day in most years, with the largest fluctuations tending to occur in summer months.

Discharge below Davis (Lake Mohave) (Figure 18), Parker (Lake Havasu), and Imperial (Imperial Reservoir) dams is also dependent on water released through each dam. Daily fluctuations based on power generation can also affect shallow-water habitats below Hoover, Davis, and Parker dams. The river that once experienced seasonal variation in flow with higher summer flows followed by winter base flows now has more static hydrographs (Figure 18) to maintain reservoir water levels and distribute water throughout the Southwest. Similarly, the Verde, Gila, and Salt rivers have been impacted through water development and experience regulated flow regimes in their lower reaches. Stability of flows may advantage some nonnative species. Given that the state of the mainstem and high numbers of nonnative fishes downstream

of Lake Mead, much effort has been exerted to create backwaters that are disconnected from the mainstem to minimize impacts from nonnative fishes and promote razorback sucker survival (Minckley *et al.* 2003; LCR MSCP 2004).

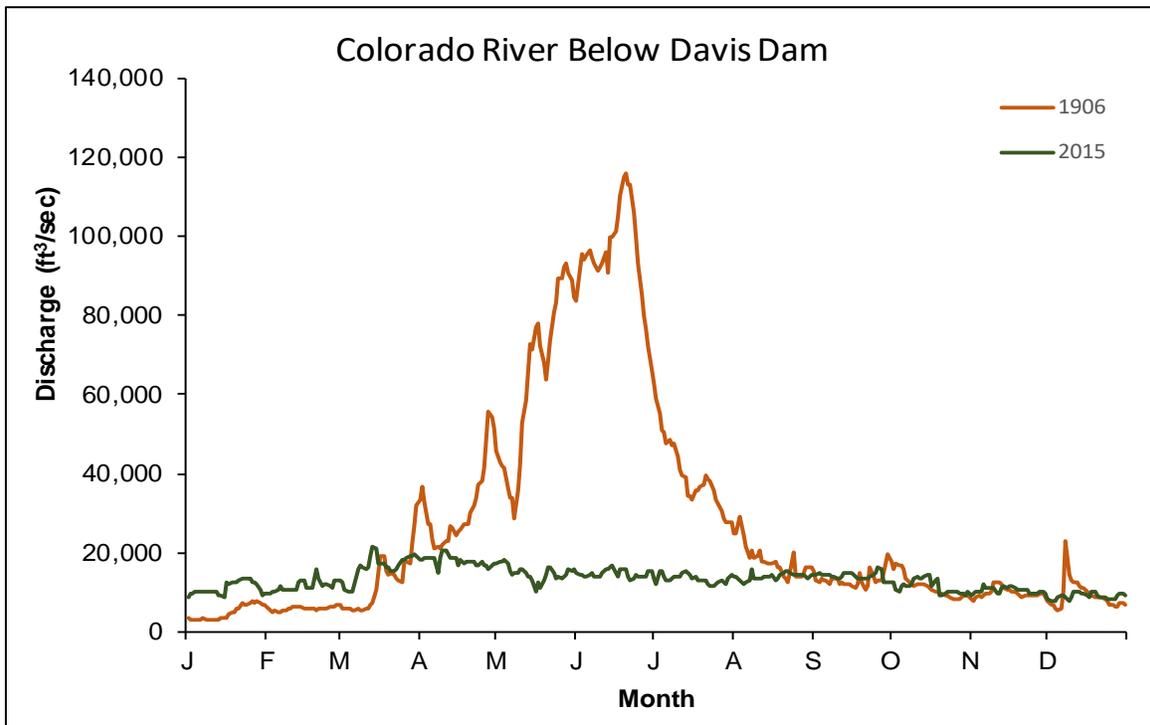


Figure 18. Mean daily discharge from the Colorado River below Davis Dam in 1906 (pre-dam) and 2015 (post-dam). Data acquired from U.S. Geological Survey (USGS) gauging station 09423000.

5.2.4 Food Supply

Research related to the abundance and availability of food for razorback sucker in the LCRB is relatively limited, but nonetheless food supply is thought to be adequate to support growth and survival in all lower basin reservoirs.

Most of research related to food supply is from the Grand Canyon and more specifically, to humpback chub. The food base in the Grand Canyon was identified as a potential limiting factor for native species (Valdez and Ryel 1995; Valdez and Carothers 1998). Food web dynamics in the Grand Canyon show longitudinal patterns correlating with large tributaries. Nonnative New Zealand mudsnails *Potamopyrgus antipodarum* and rainbow trout dominate areas below Glen Canyon dam and above the inflow of the Paria River where invertebrate production is lower, but fish production is dominated by native taxa and more similar to a stable food web below tributaries (Cross *et al.* 2013). Because of clear water releases from Glen Canyon Dam and greater light penetration, the Colorado River in Glen Canyon above the Paria River is dominated by green algae, diatoms, chironomids and amphipods. In the reaches below the Little Colorado River, the dominant taxa are blue-green algae, diatoms, chironomids, and simuliids (Hardwick *et al.* 1992; Valdez and Carothers 1998). One study on Lake Mohave and nearby backwaters showed abundance of food items and similarities in food availability for larval razorback sucker in both habitats. Differences in potential razorback sucker food items were also found from Lake

Mohave downstream to the Imperial Dam. Potential food items were greatly decreased below Davis Dam with increases in detritus, plankton, and macroinvertebrates from Lake Havasu downstream (Minckley 1979).

5.2.5 *Range and Connectivity*

In much of the LCRB, razorback sucker are restricted to specific reaches of river, specific impoundments, and in some cases to specific backwater and floodplain type habitats, mainly due to constraints imposed by predation and habitat modifications (dams) common within the LCRB (Minckley *et al.* 2003). If there is little or no movement of individuals among populations, then the number of individuals in each population is dependent on its own demographic attributes and population dynamics, or is dependent on management of these populations through augmentation or mixing (e.g., Minckley *et al.* 2003, Kesner *et al.* 2016).

Because of predation vulnerability and large dams throughout the LCRB, connectivity between populations is limited to manual translocation of fish from one population to another. Telemetry has documented movement between reservoir populations and the lotic habit upstream in both Lake Mead and in the Colorado River between Davis and Parker Dams (Lake Havasu) and from small population centers to others within each geographically defined population (Bunch *et al.* 2012; Albrecht *et al.* 2014; Kegerries *et al.* 2015).

5.2.6 Summary of Lower Basin Resource Conditions

Table 7. Summary of lower basin physical resources current condition for razorback sucker (high condition is represented by green, medium condition by yellow, low condition by orange and extirpated condition by red).

Physical Needs						
Complex Lotic/Lentic Habitat		Nonnative presence in habitat	Water Quality/Temperature	Variable Flow (lotic only)	Adequate Food	Range & Connectivity
Habitat						
Lake Mead (including Grand Canyon)	MEAD <ul style="list-style-type: none"> Spawning areas are present sufficient for reproduction to occur frequently in the lake, but shift with lake levels; razorback sucker maintain spawning areas by clearing silt Inflow areas have high turbidity which provides the majority of the cover Inundated vegetation exists dependent on lake level, juveniles use areas heavily covered by tamarisk, which may allow them to escape predation Adequate adult habitat exists and adults shift seasonally between shallow and deeper waters 	<ul style="list-style-type: none"> Nonnative predators are common in the lake and managed as sportfish 	<ul style="list-style-type: none"> Water quality is sufficient to support all life stages Water temperatures appear conducive to growth and reproduction (seasonal fluctuations; 12-29 C) 	<ul style="list-style-type: none"> Not applicable in Lake Mead 	<ul style="list-style-type: none"> Abundant food is present for all life stages in Lake Mead, resulting in high body condition factors in this population 	<ul style="list-style-type: none"> Movement occurs throughout the reservoir. Upstream and downstream movement occur between the Grand Canyon and Lake Mead proper. Movement is blocked from all other populations
	GRAND CANYON <ul style="list-style-type: none"> Spawning areas are present sufficient for reproduction to occur frequently in the Grand Canyon including tributary mouths No off channel habitat is available, connected backwaters may provide more productive environments for larvae but are not consistently available Adequate adult habitat exists; including deep pools and large areas of open water 	<ul style="list-style-type: none"> Nonnative predation/competition in Western Grand Canyon (below Lees Ferry) is rare as the community is 95% native 	<ul style="list-style-type: none"> Artificially low temperatures in Grand Canyon delay spawning in comparison to the Lake Mead population 	<ul style="list-style-type: none"> Majority of flows in Grand Canyon are stable compared to other LCRB locations, with periodic high flow events managed by Glen Canyon Dam which generally occur in the fall, outside of spawning periods 	<ul style="list-style-type: none"> Western Grand Canyon is depauperate in food base, in both quantity and diversity 	<ul style="list-style-type: none"> A significant barrier/rapid (Pearce Ferry Rapid) has formed at Pearce Ferry that could limit connectivity for fish that want to move further upstream past the rapid during low flow.
Lake Mohave (including all river below Hoover dam) LCR MSCP Reach 2	<ul style="list-style-type: none"> Spawning locations are consistent from year to year; razorback sucker annually clear silt from long-term cobble-bottomed spawning locations Limited inundated shoreline vegetation, low habitat complexity and low turbidity levels provide limited cover for juveniles Adequate adult habitat exists; including deep pools and large areas of open water 	<ul style="list-style-type: none"> Nonnative predators are dominant in the lake and managed as sportfish 	<ul style="list-style-type: none"> Water quality is sufficient to support all life stages 	<ul style="list-style-type: none"> Not applicable in Lake Mohave 	<ul style="list-style-type: none"> Adequate food is present for all life stages 	<ul style="list-style-type: none"> Movement occurs throughout the reservoir, but is blocked from all other populations.
Lake Havasu (below Davis dam to Parker dam) LCR MSCP Reach 3	<ul style="list-style-type: none"> Cobble is present and commonly used for spawning near Needles - Laughlin Complex backwater/slack water habitat available with varying levels of turbidity Connected backwaters present throughout the upper riverine portion and Topock Gorge Adequate adult habitat exists; including deep pools and large areas of open water Known populations found within the riverine section and associated backwaters 	<ul style="list-style-type: none"> Nonnative predators are dominant in the lake and managed as sportfish Large populations of striped bass and flathead catfish prevent recruitment 	<ul style="list-style-type: none"> Water quality is sufficient to support all life stages Water temperatures in the lake appear conducive to growth and reproduction (seasonal fluctuations; 12-29 C) 	<ul style="list-style-type: none"> Flows are stable below Davis Dam, reducing peak flows and modifying base flows 	<ul style="list-style-type: none"> Adequate food is present for all life stages 	<ul style="list-style-type: none"> Movement occurs throughout the reach, but is blocked from all other populations.
Colorado Mainstem Below Parker Dam LCR MSCP Reaches 4 & 5	<ul style="list-style-type: none"> Cobble bars are present in backwaters and river sections; use by razorback sucker has not been documented Complex backwaters are limited above Palo Verde Dam and become numerous below Adequate adult habitat exists; including deep pools and large areas of open water 	<ul style="list-style-type: none"> Nonnative predators are dominant in the river and prevent recruitment 	<ul style="list-style-type: none"> Water quality is sufficient to support all life stages, but typically have high salinities and high temperatures 	<ul style="list-style-type: none"> Flows are stable out of Parker dam and vary with seasonal demand, base flows have been modified Flows have been greatly reduced in these reaches 	<ul style="list-style-type: none"> Adequate food is present for all life stages 	<ul style="list-style-type: none"> Movement is blocked from all other populations by Parker Dam, Headgate Dam and Palo Verde Dam

5.3 Status of Populations

5.3.1 Upper Colorado River Basin

The UCRB basin can be subdivided into four geographic areas representing populations including the Green River subbasin, the upper Colorado River subbasin (defined as the area above Lake Powell excluding the Green River subbasin), the San Juan River subbasin, and Lake Powell.

In the UCRB, razorback sucker are primarily found in the Colorado River, Green River, and San Juan River, with the largest population occurring in the Green River. In recent years, captures and detections of razorback sucker were the results of stocking to maintain populations. Since 2000, over 560,000 razorback sucker have been stocked into the UCRB and 53,854 unique individuals have been captured or detected via PIT-tag scanner (Table 8) (STReaMS 2016). Captures refer to interactions with field staff, either at fish passage structures or active sampling methods. Detections refer the number of fish that interacted with stationary or temporary antennas which record PIT tags that pass within their range. Tributaries that historically contained razorback sucker (Yampa, White, Duchesne, and Animas rivers) harbor few individuals that are limited to lower reaches near the confluences with the Green, Colorado, or San Juan rivers. In the Green, Colorado, and San Juan rivers, razorback sucker captures and detections are widespread.

Table 8. Number of razorback sucker captured, detected, and stocked in the UCRB since 2000 (STReaMS 2016 published and unpublished data; note that at time of writing that STReaMS was still being populated and sampling effort varies among rivers).

Stream or Waterbody	Subbasin	Captured	Individuals Detected	Stocking
Total		37,936	15,918	560,186
Colorado River	Colorado	7,570	1,076	144,780
Dolores River	Colorado		30	
Gunnison River	Colorado	486	109	46,387
Roubideau Creek	Colorado		4	
Above Brennan	Green	11		
Duchesne River	Green	24		
Green River	Green	11,819	6,145	201,603
Green River Canal	Green		1,283	
Green River Wetlands	Green	1,552		8,208
Johnson Bottom	Green	46	6	
Price River	Green		74	
San Rafael River	Green	3	1,179	
Stewart Lake	Green	2,175		
Stirrup	Green	1		
White River	Green	185	66	
Yampa River	Green	8	21	30
Lake Powell	Lake Powell	661	131	73
Animas River	San Juan	52		23,192
Chaco River	San Juan	1		
Chinle Creek	San Juan	1		
Hogback Canal	San Juan		1,275	

Stream or Waterbody	Subbasin	Captured	Individuals Detected	Stocking
Total		37,936	15,918	560,186
McElmo Creek	San Juan	4	512	
Montezuma Creek	San Juan			411
San Juan River	San Juan	13,337	4,007	135,502

5.3.1.1 Green River Subbasin

The Green River is typically divided into three reaches for sampling: the middle Green from the mouth of Whirlpool Canyon to near the White River confluence (RKM 539.4-396.0), Desolation-Gray from the White River confluence to Green River, Utah (RKM 334.0-246.0) and the lower Green from Green River, Utah to the confluence with the Colorado River (RKM 193.2-0). In 1989, the middle Green River razorback sucker population was estimated at 948 adults (95% CI = 758–1,138) (Lanigan and Tyus 1989). Eight years later, the population was estimated at 524 adults (95% CI = 351–696), and was characterized as being stable or declining slowly with some evidence of recruitment (Modde *et al.* 1996). In the lower reach of the Green River, available data were insufficient to estimate numbers of razorback sucker adults (Modde *et al.* 1996). Bestgen *et al.* (2002) estimated that the population of wild adult razorback sucker in the middle Green River was about 100 based on sampling in 1998-1999. A few individual razorback sucker were captured in the vicinity of the San Rafael River confluence small numbers of larvae and juveniles indicated probable spawning. (Gutermuth *et al.* 1994; Chart *et al.* 1999; Muth *et al.* 2000; Bestgen *et al.* 2002). The extirpation of wild fish prompted stocking efforts managed by the UCREFRP.

The number of razorback sucker has been increasing in the Green River subbasin since the early 2000s through stocking. Population estimates using capture data from 2011– 2013 are available for the lower Green River, Desolation-Gray canyons, and the middle Green River. Model-averaged estimates for the subbasin peaked over 30,000 individuals in 2012 and 2013 (Figure 19; 36,355, 95% CI: 17941-74854) (Zelasko *et al.* 2018). The authors encourage caution as these estimates are based on low capture probabilities and insufficient recapture events during the study period. However, the results offer an indication of a large resident population.

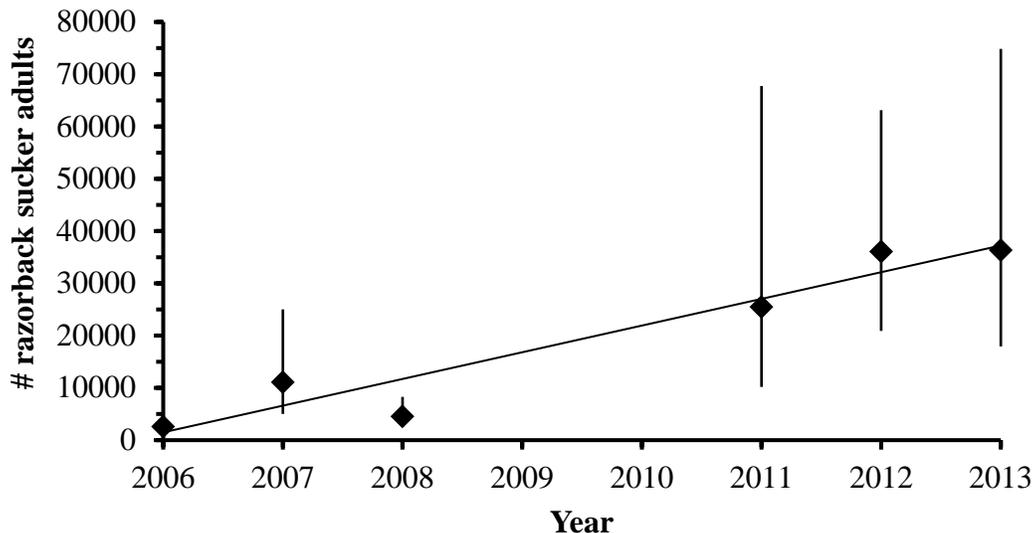


Figure 19. Model-averaged abundance estimates and 95% confidence intervals (vertical bars) for razorback sucker captured in the Green River, Utah, 2006-2013, from Zelasko *et al.* 2018.

Evidence of successful reproduction (larval drift) has been documented every year since collection began (in about 1993) in the middle Green River near Jensen, mostly below Razorback Bar. Bestgen *et al.* (2007) also documented a probable razorback sucker larva originating in Lodore Canyon, which is upstream of Razorback Bar. Larval concentrations and timing are documented annually, varying with flow and temperature (Bestgen and Jones 2017). Field crews reported the capture of unmarked juvenile individuals (114 across all in-river projects [STRaMS 2016]) indicating a limited degree of wild recruitment to this life stage in the basin. Larval fish in the lower Green River have been regularly present since 2009 when monitoring began (Badame 2009), though typically earlier in the season than in the middle Green River. Ripe razorback sucker were captured in a cobble side channel at river mile 103.7 in 2008, three age-1 juveniles (119-120 mm TL) were captured between river miles 18 and 44 in 2008 in the lower Green River (Badame 2009). Recruitment relies on relatively few and small-scale in-channel features such as flooded washes or backwaters for rearing habitat; floodplain wetland habitats are rare in this section.

Razorback sucker spawning and larval presence has been documented in tributaries to the Green River. Very low levels of spawning were documented in the Yampa River, suggesting a small population of razorback sucker exists upstream of Echo Park. Captures of razorback sucker larvae in the White River confirm spawning and the increasing range of fish stocked in the Green River (Webber *et al.* 2013). Remote PIT-tag scanning data from the San Rafael River from 2008 to 2010 showed 20 razorback sucker utilizing the river during spring runoff (Bottcher *et al.* 2013). Similar patterns have been documented in the Price River (Budy *et al.* 2017). Use of the Duchesne River by razorback sucker was suggested by migration of a radio-tagged razorback sucker into the tributary (Tyus *et al.* 1981).

Implementation of the LTSP (LaGory *et al.* 2012) has shown success through larval entrainment and survival to juvenile size classes in flooded wetlands in recent years (Jones *et al.* 2015; Schelly and Breen 2015). From 2013-2018, Stewart Lake floodplain (near Jensen, Utah) was managed to encourage razorback sucker recruitment in conjunction with LTSP flows. The wetland is kept dry and therefore free of nonnative predators until managed spring flows triggered by razorback sucker larval presence flood the wetlands. Inflows were screened to prevent nonnative predator introduction. The wetland is maintained with supplemental water through the summer and then drained into the Green River in the fall. During each annual draining event, young-of-year razorback sucker were captured in a fish trap and released back into the river, with the largest cohort occurring in 2016 (Table 9) (Schelly *et al.* 2016). The growth of razorback sucker in Stewart Lake may improve these individuals' chances of overwinter survival (Schelly *et al.* 2014). Conditions in Stewart Lake changed annually based on habitat conditions, available flow, number of larvae available to be swept into the wetland during the spring peak flow and number of days the wetland was operational (Skorupski *et al.* 2013; Schelly *et al.* 2014; Schelly and Breen 2015; Schelly *et al.* 2016; Staffeldt *et al.* 2017b). In spring 2018, dense cattail stands were burned in an attempt to restore previous habitat available to growing larvae.

Table 9. Wild-produced razorback sucker sampled and released as young-of-year from Stewart Lake.

Year	Count
2013	592
2014	749
2015	97
2016	2110
2017	2

LTSP represents a major step forward in the recovery of the species. The method of entrainment has been repeated at Johnson Bottom, Sheppard Bottom and Wyasket Lake resulting in varying degrees of success, none of which match the success of Stewart Lake. Adult recruitment in the basin is rare, if present. Untagged adults have been found (223 from 2010-2017), but at levels that could likely be attributed to tag loss and not recruitment. The lack of recruitment is thought to be a result of predation by large-bodied fish (northern pike, smallmouth bass, and walleye), competition and predation in wetlands among small-bodied fish, the relatively new implementation of LTSP and other flow recommendations and other factors.

Stocking of razorback sucker continues at robust levels in the upper basin. Since 2000, more than 209,000 fish were stocked into the Green River subbasin (STReAMS 2016). Razorback sucker averaging 252.5 mm TL stocked into the UCRB from 1995–2005 survived their first year in the river at a rate of 0.05 (when averaged across stocking season) while 300-mm-TL fish were estimated to survive at a rate of 0.15 (Zelasko *et al.* 2011). Similarly-sized razorback sucker (average length 300 mm) stocked during the 2004–2007 study period had an estimated mean initial (first year) survival rate of 0.09 and subsequent survival ranging from 0.79-0.94 depending on rearing environment (Zelasko *et al.* 2011). The Revised Integrated Stocking Plan (Integrated Stocking Plan Revision Committee 2015) now recommends stocking 6,000 fish into the Green River annually with average sizes exceeding 350 mm TL.

Genetic diversity is not a concern in this population as genetics are maintained through broodstock management. However, all upper basin populations have lower genetic diversity than populations in the lower basin (Dowling *et al.* 2012). Hybridization risk is low in the Green River, however, hybridization with nonnative white sucker among flannelmouth and bluehead sucker may be increasing in some areas of the subbasin, including the Lodore/Whirlpool reach (Bestgen *et al.* 2007). Experts believe that white sucker hybrids may increase the likelihood of hybridization with all sucker species (Bestgen *et al.* 2007). Abundance of hybrid combinations have increased over time (Bestgen *et al.* 2007). Particularly common were hybrids that had white sucker as one parental type. Occurrence of white suckers and hybrids declined in a downstream direction in Lodore Canyon.

Although the population in the Green River is robust and incidents of human-aided juvenile recruitment are increasing, concerns regarding the stability of the population remain. The Green River population is stable only through annual stocking efforts. The population is not self-sustaining and likely to decrease quickly should stocking efforts cease.

5.3.1.2 Colorado River Subbasin

The Colorado River subbasin encompasses the Colorado, Dolores and Gunnison rivers and their tributaries and ends at the inflow to Lake Powell. The number of wild razorback sucker captured in the Colorado River subbasin has been low since the 1970's (McAda 2003). The greatest number of razorback sucker captured in this subbasin was in 1975 with 206 individuals captured. Between 1990 and 2003, only 11 wild razorback sucker were captured, all of which were brought into captivity and incorporated into the propagation program (McAda 2003).

The number of razorback sucker encountered in the basin has been increasing as stocked fish survive and accumulate. Monitoring in the Colorado River occurs in conjunction with Colorado pikeminnow sampling, which are conducted for three consecutive years followed by two years without sampling, after which surveys resume. In 2008-2010, preliminary population estimates ranged from 2,449-4,895 adult individuals. Sampling in 2013-2015 produced preliminary population estimates ranging from 5035-8078 for the same reach (Colorado River between Palisade and the confluence with the Green River in Utah; Figure 20, Elverud *In prep*).

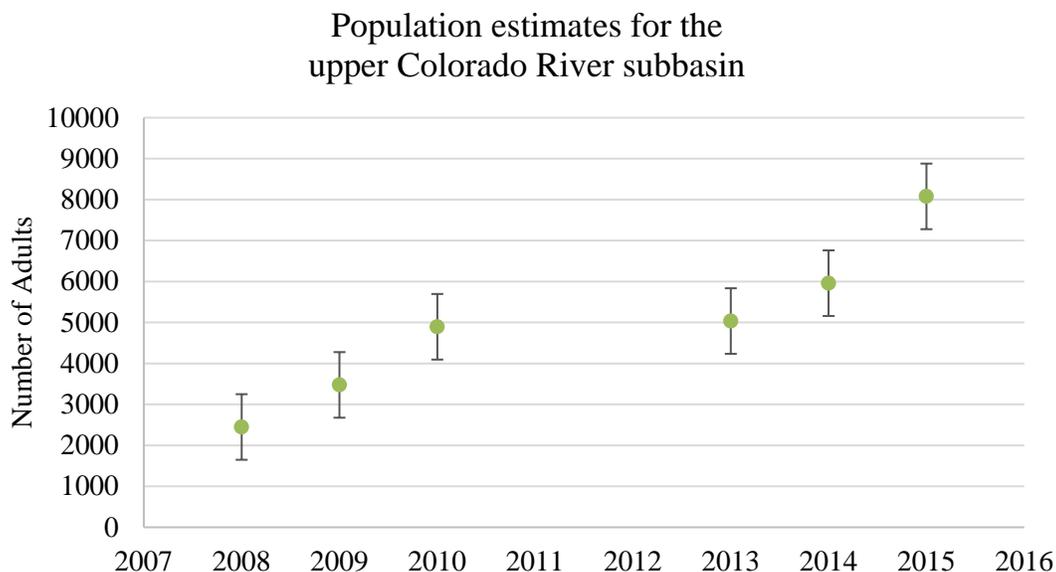


Figure 20. Razorback sucker population estimates (and 95% CI) by year for the Colorado River between Palisade and the confluence with the Green River (preliminary estimates from data gathered during Colorado pikeminnow sampling) as presented in Elverud *in prep*.

As evidenced by ripe fish and larval collections, razorback sucker spawning is currently occurring throughout the Colorado River subbasin. Ripe fish and larvae have been collected in the '15 and 18-mile reaches' of the Colorado River through the Grand Valley and in 30 miles of the Gunnison River directly above the confluence with the Colorado River (Elverud *in prep*; D. B. Osmundson and Seal 2009). Access to the Gunnison River has been restored by the UCREFRP by the construction of a fish ladder, trap and daily sorting to prevent nonnative fishes from accessing the river. Razorback sucker also appear to be regularly present during spring runoff in the Dolores River, suggesting spawning activity (David Speas, U.S. Bureau of Reclamation, personal communication, March 2018).

Recruitment to the juvenile stage in the Colorado basin is rare, but has been confirmed at low levels. In 2012, three young-of-year fish were captured in the Colorado River, and another fish confirmed to be wild was found in an off-channel pond. In 2013, 39 razorback sucker juveniles were caught during monitoring targeting Colorado pikeminnow (Francis, Ryden *et al.* 2013b). The juvenile fish were collected across almost 70 river miles, in the months of May and June under a variety of flow conditions (Francis *et al.* 2013b). A single juvenile (115 mm TL) was collected just below Westwater Canyon in 2018 (Travis Francis, U.S. Fish and Wildlife Service, personal communication, May 2018). Recruitment from juveniles to adults is rare. If occurring in the basin, it is most likely due to persistent predation from nonnative fishes and lack of rearing habitat. Several untagged adults have been found, but could be attributed to tag loss.

Since 2000, 191,000 razorback sucker have been stocked into the Colorado River subbasin. Prior to 2013, the Colorado River received approximately 10,000 stocked fish per year and the Green River received almost 20,000 fish. In 2015, the Revised Integrated Stocking Plan (Integrated Stocking Plan Revision Committee 2015) changed guidance to reduce stocking numbers, but increase size of the fish stocked. The Ouray National Fish Hatchery in Vernal, Utah and the

Ouray National Fish Hatchery in Grand Junction, Colorado currently each produce 6,000 razorback sucker with average lengths of 350 mm or more. In most years, stocking events are split between the Green and Colorado subbasins.

Razorback sucker stocked from 1995–2005 have demonstrated better survival when they are stocked in the fall, winter and spring and at larger sizes (greater than 300 mm) (Zelasko *et al.* 2009). First year survival across all size classes ranged between 0.07 and 0.08 when not stocked during the summer months. Overall survival rates through subsequent intervals was estimated at 0.75 (95% CI: 0.688-0.801) (Zelasko *et al.* 2009). The collection of larvae indicated that these stocked fish were behaving as wild fish by migrating and spawning in the Gunnison and Colorado rivers (D. B. Osmundson and Seal 2009).

Genetic diversity is not a concern in this population as genetics are maintained through broodstock management. Since 2000, 88 razorback sucker hybrids have been captured in the Colorado basin, all of which have been identified as razorback x flannelmouth, razorback x bluehead or razorback x flannelmouth x bluehead crosses (STReaMS 2016). Hybrids represent less than 0.1% of razorback sucker captured in the basin, which is not considered a threat to genetic diversity. Most captures have occurred since 2012, but it is unclear as to whether or not the pattern stems from increasing hybridization or better field identification by biologists.

In summary, this razorback sucker population has been increasing over time, but increases are driven by improved stocking success. Recruitment of fish to the adult life stage is rare and suppressed by the continued presence of nonnative fishes and lack of rearing habitat in most rivers. The population is not self-sustaining and is reliant on continued stocking.

5.3.1.3 San Juan River Subbasin

In the San Juan River, the long-term monitoring catch-per-unit-effort for adult razorback sucker has been steadily increasing since 2003 due to stocking; since 2010 catch rates have been significantly higher than catch rates during 2003–2009 (Schleicher 2016). Population estimates for razorback sucker have been developed for the San Juan River from Shiprock, New Mexico to Sand Island, Utah (approximately 70 river miles) using capture data from various sampling efforts (Figure 21). The estimates indicate the razorback sucker population in the San Juan River is relatively stable around 3000 adults (San Juan River Basin Recovery Implementation Program 2017). The vast majority of the fish used in the estimate were stocked razorback sucker, but untagged fish were captured during data collection were used in the estimates.

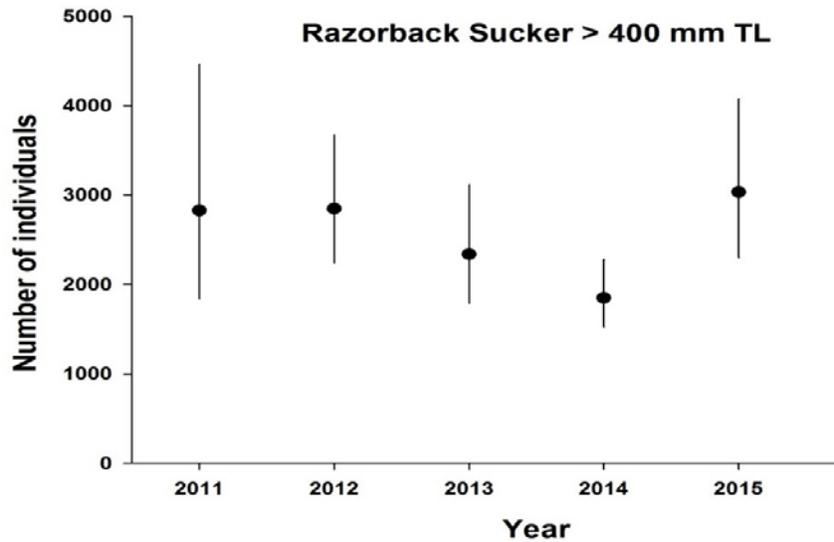


Figure 21. Population estimates for adult (> 400 mm TL) Razorback Suckers) razorback sucker in the San Juan River above the waterfall from 2011-2015 (San Juan River Basin Recovery Implementation Program 2017). Error bars represent 95% confidence intervals.

Razorback sucker spawning and subsequent larval presence has been documented in the San Juan River annually since 1998 (Farrington *et al.* 2018), however the percentage of adults participating in spawning in any given year is low (~2% of the adult population) (Diver and Wilson 2018). Larval collections have been relatively stable over the last decade and larvae are distributed throughout the reaches sampled on the San Juan. Opercular deformities have been seen in larvae at rates of 17.6% in 2016 and 13.1% in 2017, which are higher than in other native species (Farrington *et al.* 2018). The causes of the deformities are unknown but could be attributed to temperature, nutrition or contaminants (Barkstedt *et al.* 2015).

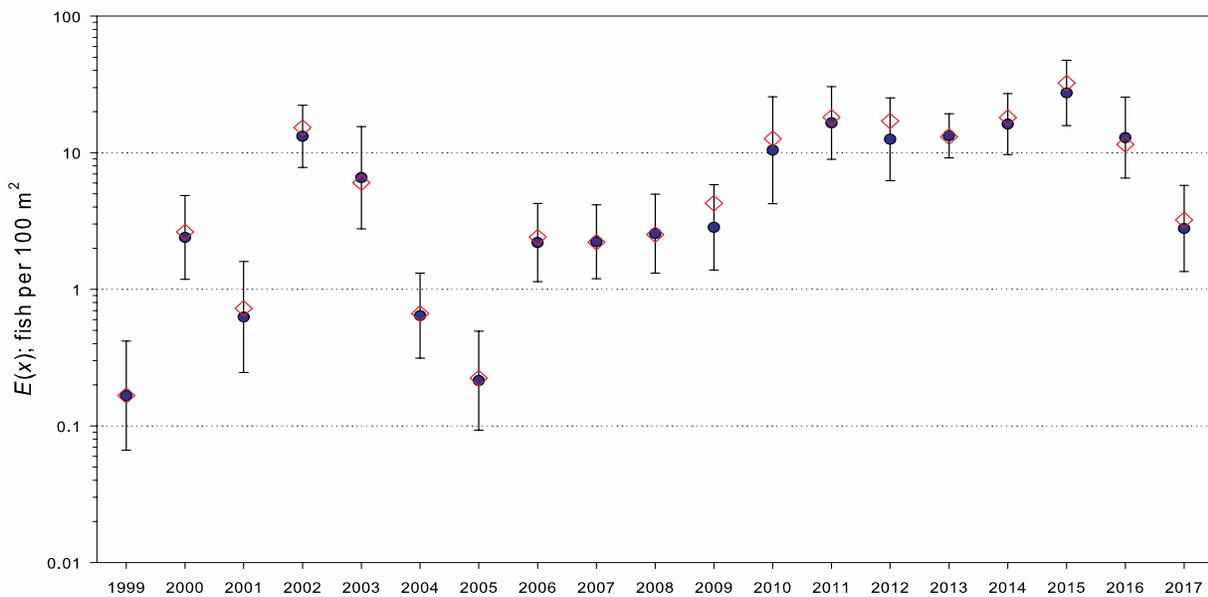


Figure 22. Razorback sucker estimated larval densities (noted by $E(x)$) in the San Juan River over time (Farrington *et al.* 2018). Solid circles indicate estimates and error bars represent 95% confidence intervals Red diamonds indicate simple estimates of mean densities using the method of moments.

Larval collection rates are comparable to those of other sucker species native to the San Juan basin early in the season (April-May), a trend that does not continue into summer months or more advanced life stages (Figure 23). Reasons for this decline are currently being explored by the SJRIP.

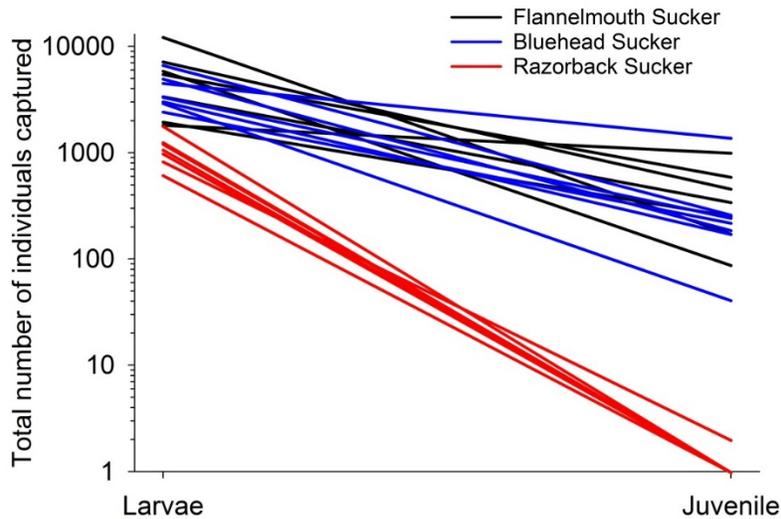


Figure 23. Number of larvae and juvenile sucker species captured in the San Juan River (San Juan River Basin Recovery Implementation Program 2017).

Recruitment to both the juvenile and adult life stages is rare in the San Juan subbasin. Current theories regarding the lack of recruitment include high emigration, the limited number of spawning adults, and a lack of available rearing habitat, all of which are being explored by the SJRIP.

The population remaining in the San Juan subbasin is maintained by stocking efforts and is not self-sustaining. Planning documents mandate the annual stocking of 11,400 razorback sucker greater than 300 mm TL. More than 159,000 razorback sucker have been stocked in the San Juan between 2000 and 2017 (STReaMS 2016).

Genetic integrity is currently managed by the propagation efforts of SJRIP and therefore inbreeding should not be a concern as long as the program is maintained. Should survival of young increase without a corresponding increase in the number of adults participating in spawning, inbreeding may become a concern. Hybridization with other sucker species can occur, but is rare in the basin.

5.3.1.4 Lake Powell

Many questions remain regarding the role of Lake Powell in the Upper Basin populations; it is likely that razorback sucker in the Colorado River and San Juan River inflow areas are extensions of populations found in the Green, Colorado and San Juan rivers rather than an independent population. It is important to note that evaluating the riverine populations with the inclusion of Lake Powell information may provide a more complete picture of population

dynamics, but data are not currently available to make conclusions. Lake Powell is not regularly monitored like the other three upper basin populations and much uncertainty remains about the status of this population. Although it is suspected to be a promising location for razorback sucker, more research and monitoring are needed.

Traditional population estimates are not available for the entire population of Lake Powell, but population estimates have been developed for portions of the lake (Table 10). Catch per unit effort data is also available for both arms of Lake Powell (San Juan arm = 0.017 fish/net-hour [SE=0.003], Colorado arm = 0.067 fish/net-hour [SE=0.006]). These levels are similar to Lake Mead (range of 0.07-0.092 fish/net-hour) (Albrecht *et al.* 2017).

Table 10. Recent adult razorback sucker population estimates for various areas in Lake Powell.

Location	Years Sampled	Point Estimate	95% Confidence Interval	Source
Lake Powell (Colorado River arm)	2010-2016	2,184	1,784–2,713	Albrecht <i>et al.</i> (In prep)
Lake Powell (San Juan River arm)	2011-2012	527	248–1,311	Francis <i>et al.</i> 2015
Lake Powell (San Juan River arm)	2017	572	549–595	Cathcart <i>et al.</i> (In press)

Available data confirms exchange of individuals between Lake Powell and all three other populations, leading to the conclusion that the inflow areas could be extensions of the other basin populations. Lake Powell is assessed here as a “population” for two reasons: population estimates exist for areas of the lake itself and the degree of connection to any other population is difficult to define. The two major inflow areas (the San Juan River and Colorado River) display characteristics that likely provide suitable habitat for razorback sucker recruitment. It is likely that these large, turbid, warmer lentic environments are functioning similarly to historic backwaters, floodplains, oxbows, and isolated off-channel ponds where reproduction and recruitment historically occurred (R. S. Wydoski and Wick 1998; Mueller *et al.* 2001; Mueller 2006). Recent studies documented inflows of the Colorado River and some of its reservoir tributaries as harboring spawning, and perhaps razorback sucker populations recruiting to the adult life stage (Francis, Ryden *et al.* 2013a; Francis *et al.* 2015; Kegerries *et al.* 2015).

Reproduction appears to be occurring annually and larval razorback sucker have been captured in inflow areas (Francis *et al.* 2015; Albrecht *et al.* 2017). Reproduction also is occurring upstream of inflows to Lake Powell, which may supply additional larvae to the reservoirs via larval drift, but recruitment has yet to be confirmed.

Multiple studies indicate the presence of untagged fish in the San Juan arm of Lake Powell. Sampling events in 2011–2012 noted 36% of individuals (53 adults) captured were untagged (Francis *et al.* 2015). In a separate study conducted from 2010-2016, 44% of individuals (72 adults) captured were untagged and fin ray aging data indicated ages of 7-17 years, or potential recruitment years between 1992 and 2005 (Albrecht *et al.* 2017). A third study in 2017 captured

183 fish, 19% (34 adults) of which were untagged (Cathcart *et al.*). Razorback sucker stocked in the upper basin are typically adults with lengths >350 mm, but approximately 10,000 fish were released untagged in the San Juan River in 2006-2007. The fish released untagged were in distress and concern was expressed that they would not survive tagging. SJRIP tracks untagged fish in the San Juan River over time and saw an increase to almost 40% in 2006 (Table 11). Captures of untagged fish have lessened in recent years in the San Juan River, plateauing below 10% (Durst 2017). The untagged fish in Lake Powell do not prove recruitment is occurring, but the San Juan arm of Lake Powell is the only place in either basin where rates of untagged fish approach the levels documented in Lake Mead (59%) where recruitment is occurring (Albrecht *et al.* 2010). In addition, a single report documents the presence of 5 wild-recruited adults in the San Juan arm of the waterfall presumed to have been from 2008 and 2009 year classes (Barkalow and Platania 2017), but the results presented have not been widely accepted.

Table 11. Number and percentage of untagged Razorback Sucker razorback sucker captured by year in the San Juan River (Durst 2017).

Year	Total	Individuals captured			
		With PIT tags (stocked)	With PIT tags (tagged in field)	Without PIT tags	Percent without PIT tags
2004	415	381	0	34	8.2
2005	343	305	4	34	9.9
2006	561	340	8	213	38.0
2007	1104	707	40	357	32.3
2008	604	381	39	184	30.5
2009	698	439	75	184	26.4
2010	1117	873	80	164	14.7
2011	1713	1375	84	254	14.8
2012	2210	1797	96	317	14.3
2013	1927	1617	126	184	9.5
2014	1502	1256	118	128	8.5
2015	1827	1558	111	158	8.6
2016	1778	1519	105	154	8.7

In the Colorado River arm of Lake Powell (2014–2015), nearly 90% of fish are recaptures (Albrecht *et al.* 2017). Ongoing studies will assess whether the remaining 10% infers local recruitment or emigration from the San Juan arm or upstream rivers into the Colorado River arm. Razorback sucker are not currently stocked in Lake Powell, though many individuals stocked in the Green, Colorado and San Juan are captured or detected in the lake.

Razorback sucker movement between the San Juan arm and the Colorado River arm has been documented (Francis *et al.* 2015; Durst and Francis 2016), demonstrating that the populations within Lake Powell intermix, at least to some degree, and may warrant sampling and calculating lake-wide population estimates. Movement was documented during just a few days when lake levels increased sufficiently to allow for upstream movement of Lake Powell fish back into the San Juan River (Francis *et al.* 2015). Upstream movement of six individuals was documented (up to 180 miles up the San Juan River from Lake Powell), while downstream movement of fish stocked into the San Juan River was also documented (Francis *et al.* 2015; Durst and Francis 2016). Movement of Lake Powell razorback sucker among subbasins has also occurred. Between

2014 and 2017, 927 fish were documented in the Colorado River arm area (Francis *et al. In prep*). One-hundred fifty-two of them were captured in the same location in multiple years, 87 were reencountered in the Green subbasin, two were reencountered in the Colorado subbasin, and 27 were reencountered in the San Juan arm area (Francis *et al. In prep*). Razorback sucker in the San Juan River arm, much like what has been documented in the CRI and LGC (lower Grand Canyon), congregate at the base of the waterfall currently blocking movement into the San Juan River, indicating a preference for upward movement into the river. Additional efforts since these surveys have documented 716 individual razorback sucker at the San Juan River waterfall. At least 15 of those individuals moved from the Colorado River mainstem (Mark McKinstry, U.S. Bureau of Reclamation, personal communication, March 2018).

Genetic assessments indicate that allelic richness is higher in Lake Powell than in the Green or Colorado subbasins, with values approaching that of the lower basin (Dowling *et al. 2012*). Presence of other sucker species is limited, but flannelmouth sucker, bluehead sucker and flannelmouth x razorback hybrids have been found in both the Colorado and San Juan arms (Travis Francis, U.S. Fish and Wildlife Service, personal communication, May 2018).

In summary, the status of the population in Lake Powell is still very much in question and as a result, is grayed out in the current condition tables (Table 6 and Table 12). Population estimates in various areas of the lake show there are likely resident populations as well as transitory fish between Lake Powell and the associated river systems. Studies in recent years suggest that recruitment in this system may be occurring, but limited sampling efforts to date have been unable to confirm recruitment in Lake Powell. Additional sampling is planned to assess the condition of the population in the San Juan arm.

5.3.1.5 Summary of Current Demographic Conditions for Upper Basin Populations

Table 12. Summary of upper basin demographic current condition for razorback sucker (high condition is represented by green, medium condition by yellow, low condition by orange and extirpated condition by red).
The gray box around Lake Powell is meant to indicate a lack of scientific data in comparison with other upper basin populations.

Population	Demographics					
	Adult population size (wild + stocked fish)	Spawning and larval presence	Recruitment	Dependence on stocking	Genetic integrity (inbreeding or hybridization)	Population stability (wild recruited adults)
Green River Subbasin (plus Lake Powell)	<ul style="list-style-type: none"> Low precision estimate of 36,355 (95% CI: 17941-74854) stocked adults (2011-2013) up from a few 100 wild fish in the 1990's 	<ul style="list-style-type: none"> Spawning and egg production are documented annually since 1993 Larvae are present and abundant in the river and have been increasing in recent years 	<ul style="list-style-type: none"> Juvenile recruitment has been documented consistently as a result of intense management actions. Juveniles were produced in Stewart Lake in 2013-2017, but have been difficult to track with current sampling efforts Juveniles have been found in the lower Green River in multiple years, but sightings are rare Adult recruitment is rare, some small adults have been found, but levels of untagged adults could be attributed to tag loss 	<ul style="list-style-type: none"> > 6,000 adults (average length >350 ml) are stocked into the Green River mainstem annually 	<ul style="list-style-type: none"> Genetic integrity is managed through stocking efforts, inbreeding has not been a concern Hybridization with native flannelmouth sucker can occur; increased hybridization between White and native suckers may eventually increase risks to razorback sucker; white sucker are more likely to occur in cooler waters Hybridization rates among all suckers have been increasing since 1980 in Lodore Canyon 	<ul style="list-style-type: none"> Wild populations are too low to measure Stocked adult population is stable and increasing through annual augmentation efforts Recent reports indicate that without continued stocking, populations are likely to decrease quickly
Colorado River Subbasin (plus Lake Powell)	<ul style="list-style-type: none"> Basinwide estimates for 2013-2015 show an increasing population trend from 5035 (CI 95%: 3755-6315) to 8078 (CI 95%: 6731-9421), due entirely to survival of stocked individuals. 	<ul style="list-style-type: none"> Monitoring of early life stages is limited, a report is currently pending Spawning has been documented in the Gunnison River and in the mainstem Colorado through the '15 and 18-mile reaches' Presence during spring runoff suggests spawning in the Dolores River Larvae are present, but widely-dispersed and low in number despite a strong stocking presence in the system 	<ul style="list-style-type: none"> Recruitment is rare, but juvenile presence has been documented Three young-of-year fish were caught in 2012 and presence of one wild fish was found in one off-channel pond. In 2013, 39 juvenile sucker were caught in the Colorado (RM 83.9-14). Untagged adults in the Colorado River are rare and are likely because of tag loss 	<ul style="list-style-type: none"> > 6,000 adult (average length >350 mm) are stocked into the Colorado and Gunnison rivers annually 	<ul style="list-style-type: none"> Genetic integrity is managed through stocking efforts, inbreeding has not been a concern Hybridization with native flannelmouth sucker can occur; increased hybridization between White and native suckers may eventually increase risks to razorback sucker; white sucker are more likely to occur in cooler waters 	<ul style="list-style-type: none"> Wild populations are too low to measure Stocked adult population is stable and increasing through annual augmentation efforts
San Juan River Subbasin (plus Lake Powell)	<ul style="list-style-type: none"> Consistent estimates of approximately 3000 adults from Shiprock, New Mexico to Sand Island, Utah (approximately 70 river miles) Almost entirely stocked individuals 	<ul style="list-style-type: none"> Spawning occurring annually Successful spawners may be only 2% of adults, indicating a potential bottleneck Larvae are present and abundant in the river, producing numbers comparable to other native sucker species Larvae are present in the inflow areas of the San Juan into Lake Powell in small numbers Larvae show higher levels of opercular deformities than other native species; the effects of which are unknown 	<ul style="list-style-type: none"> Some evidence indicates that limited juvenile recruitment is occurring, Untagged adults in the San Juan River are rare and are likely because of tag loss 	<ul style="list-style-type: none"> 11,400 adults are stocked annually 	<ul style="list-style-type: none"> Genetic inbreeding has not been a concern Hybridization with flannelmouth sucker can occur, but is rare Successful spawners may be only 2% of adults, indicating a potential bottleneck 	<ul style="list-style-type: none"> Wild populations are too low to measure Population is stable and increasing through annual augmentation efforts
Lake Powell (including inflow areas and the lake proper)	<ul style="list-style-type: none"> San Juan arm: 667 (95% CI: 442–1,061) Colorado arm: 2,184 (95% CI: 1,748–2,713) 572 ripe adults (SE = 11.7, 95% CI = 549–595) just below the San Juan Waterfall. It is possible / likely that each arm of Lake Powell is an extension of the river above it (similar to LCRB populations), experts expect estimates are low and are investigating further 	<ul style="list-style-type: none"> Spawning and egg production has been documented at many sites Larvae are present in small numbers from fish spawning in Lake Powell Larvae are present in larger numbers in the Colorado arm 	<ul style="list-style-type: none"> Recruitment has not yet been definitively documented, but it is suspected at low levels High percentages of adult fish are captured without tags, suggesting that recruitment to adult stages is occurring in the lake, but this has not been confirmed 	<ul style="list-style-type: none"> No stocking occurs in Lake Powell, but most individuals found in the lake were stocked in one of the three upstream river systems 	<ul style="list-style-type: none"> Inbreeding has not been a concern, genetic diversity is higher than in any other upper basin population Few other sucker species are present, so hybridization is not a concern 	<ul style="list-style-type: none"> Status of this population is unknown Further work is needed to examine whether this population should be considered independent or as integrated with upstream populations

5.3.2 Lower Colorado River Basin

In the LCRB, razorback sucker can be found from the lower Grand Canyon downstream to the Imperial Dam on the Colorado River, as well as in the Verde River in small numbers and with limited survival. More than 12 million razorback sucker have been stocked into the LCRB; their retention and survival were primarily restricted to reservoir populations and a few other populations found in the mainstem river, including backwater, and impoundment-type locations near Lake Mohave, Lake Havasu, and the Cibola and Imperial National Wildlife Refuges. The focus of reservoir stocking has moved towards stocking large adults and has resulted in adult survival, whereas the majority of early stockings focused on stocking juvenile fish that did not reach adulthood.

The LCRB is assessed as four individual populations: Lake Mead (including the Colorado River inflow/Grand Canyon), Lake Mohave, the Colorado River between Davis and Parker dams (Lake Havasu) and the Colorado River mainstem below Parker Dam.

5.3.2.1 Lake Mead

The razorback sucker population in Lake Mead is the only population in the Lower Colorado River Basin in which there is evidence of natural recruitment. The population apparently benefited from abundant habitat during the initial filling of the reservoir prior to a rapid decline that began in the 1970s (Albrecht *et al.* 2010). Based on data obtained from aging of 509 adults and subadults captured during 1996-2016, recruitment occurred in pulses during the 1980's (Mohn *et al.* 2017). Recruitment of wild origin razorback sucker was documented near annually in Lake Mead between the 1970's and the 1990's (Mohn *et al.* 2015). Reproduction and natural recruitment has been documented annually in turbid inflow areas (i.e., Las Vegas Bay, Echo Bay, and the inflow area of the Virgin and Muddy rivers) since the 1990s (Albrecht *et al.* 2010). Razorback sucker in the Lake Mead population migrate to and from upstream portions of the Colorado River, as evidenced by larvae captured and telemetry data collected during recent monitoring surveys in the Grand Canyon (Kegerries *et al.* 2017). Reliable estimates of the size of the Grand Canyon subpopulation have been elusive due to low numbers of PIT-tagged individuals recaptured in monitoring surveys, but growth rates and recruitment are indicative of a resident population (Mohn *et al.* 2015).

Despite the dominance of nonnative fishes in Lake Mead, razorback sucker continue to reproduce and recruit naturally on an annual basis (Albrecht *et al.* 2010; Mohn *et al.* 2015; Kegerries *et al.* 2015). Although documented predation of juvenile razorback sucker by nonnative fishes has occurred (Kegerries *et al.* 2015), predation and competition do not appear to be a limiting factor in the viability of the Lake Mead razorback sucker population but may limit the population size. Cover in the form of turbidity and submerged vegetation in inflow areas seems to be the key feature of Lake Mead that provides necessary conditions for survival and recruitment of larvae and juveniles despite the presence of a full suite of nonnative fishes (Albrecht *et al.* 2017). The population is likely to persist as long as these conditions are maintained.

Within the Lake Mead inflow areas 59% of individuals (325 adults) captured between 2010 and 2016 were new, wild, untagged fish (Albrecht *et al.* 2017). Razorback sucker in the Grand

Canyon appear to be rare, however, recent research shows movement of telemetered fish from Lake Mead into the lower Grand Canyon and limited captures of adult razorback sucker (Bunch *et al.* 2012; Albrecht *et al.* 2014; Rogowski and Wolters 2014; Kegerries *et al.* 2015). Additionally, razorback sucker spawning within the Grand Canyon or its tributaries was documented in 2014 and 2015 (Albrecht *et al.* 2014; Kegerries *et al.* 2015). It is unclear whether razorback sucker in the Grand Canyon are an extension of the Lake Mead population, but connectivity does exist between the two and therefore they will be considered a single population for the purposes of this report.

In Lake Mead, the CRI below the Grand Canyon, Virgin/Muddy River inflow area, and Las Vegas Wash provide spawning and recruitment habitat for razorback sucker. Reproduction is occurring annually and larval razorback sucker are being captured at all three locations (Kegerries *et al.* 2015; Mohn *et al.* 2015). Reproduction occurring upstream of Lake Mead in the CRI supplies additional larvae to the reservoirs via larval drift (Kegerries *et al.* 2015; Farrington *et al.* 2018).

In Lake Mead, trammel netting data from 2010-2017 yielded estimates between 400 and 600 individuals for Lake Mead and the CRI (Figure 24) (Albrecht *et al.* 2013a; Albrecht *et al.* 2014; Mohn *et al.* 2017). The recapture rate for that same time was 45% (Albrecht *et al.* 2013a, 2013b; Albrecht *et al.* 2014b). An estimate of annual apparent survival of 0.80 (95% CI=0.45–0.95) was derived from razorback sucker captures from 1996 to 2015 (Mohn *et al.* 2015).

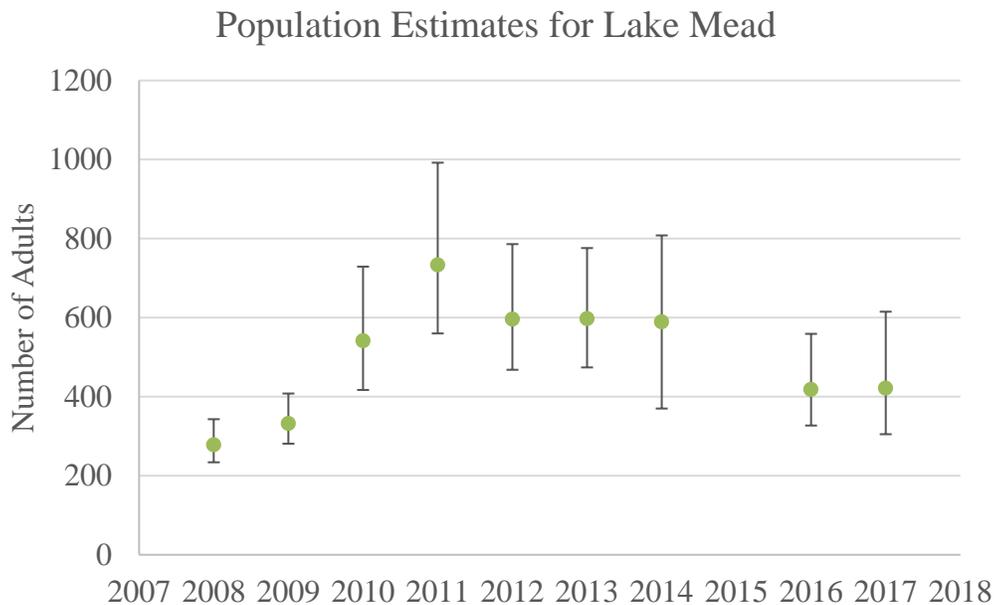


Figure 24. Razorback sucker population estimates for all individuals at large >1 year in Lake Mead by year, with error bars representing 95% confidence intervals.

In Lake Mead, razorback sucker movement among spawning areas during the spawning season and between years has been documented. More interesting still is movement into and out of Lake Mead by telemetered razorback sucker. From 2010 to 2012, three of five sonic-tagged razorback sucker moved from the lake proper at the mouth of CRI upstream into the mainstem river

(Albrecht, Kegerries *et al.* 2010; Kegerries and Albrecht 2011; Kegerries and Albrecht 2013). Additional sonic-tagged razorback sucker released both in the river and within the lake moved upstream and downstream, with some utilizing both the river and the lake annually. Sonic-tagged razorback sucker movement data to date shows use of the Grand Canyon from near Pipe Creek downstream into Lake Mead (Albrecht *et al.* 2014; Kegerries *et al.* 2015; BIO-WEST, unpublished data).

The Lake Mead razorback sucker population, although recruiting, is not as genetically diverse as the Lake Mohave population and shows variability in diversity and relatedness by spawning location and years. Persistent low population numbers are causing concern over genetic diversity and augmentation from Lake Mohave is being considered as a management action (James Stolberg, LCR MSCP, personal communication, July 2018).

In summary, Lake Mead is the only location where recruitment is occurring despite an abundance of nonnative fish. The population remains small which is causing concern about its long term persistence and the potential development of genetic bottlenecks. The LCR MSCP monitors the population regularly, but does not currently perform management actions to support the population.

5.3.2.2 Lake Mohave

The Lake Mohave population is supported by stocking of captive-reared fish from wild-spawned larvae and remains an important genetic refuge for razorback sucker. Approximately 60,000-75,000 naturally-occurring razorback sucker inhabited Lake Mohave during the 1980s, but the population declined to the point that fewer than 3,000 adults were thought to be present in the reservoir by 2001. The original wild population declined to less than 250 individuals by 2011 and has now been entirely replaced by adults that were reared in hatchery facilities and nearby grow-out ponds (Kesner *et al.* 2016).

Adult population estimates based on mark-recapture data involving PIT tagged fish recaptured during trammel net monitoring surveys were 2,230 individuals in 2015 (95% CI = 603, 3897), 1,707 (95% CI = 922, 5936) in 2016, 1,291 (95% CI = 531, 3436) in 2017 (Wisnall *et al.* 2015; Wisnall *et al.* 2016; Leavitt *et al.* 2017). Estimates using remote PIT scanning and mark-recapture models (Figure 25) were 3,572 individuals (95% CI 3,341-3818) in 2015 and 3,815 (95% CI 3,573-4,073) individuals in 2016 (Wisnall *et al.* 2015; Wisnall *et al.* 2016; Leavitt *et al.* 2017); indicating that continued stocking that began in the 1990s has preserved the population, but has not led to restoration of previous population levels (Marsh *et al.* 2003). The current population is made up of surviving individuals from stockings of more than 200,000 razorback sucker that were reared from larvae captured throughout the reservoir during the spawning season and transferred to hatchery facilities. Survival of stocked individuals is size-dependent, and adaptive management based on survival data led to an increase in the minimum size of stocked fish from 250 mm to 350 mm by 2004; and now > 500 mm TL is thought to be the optimal size for stocked individuals to escape predation by nonnative fish.

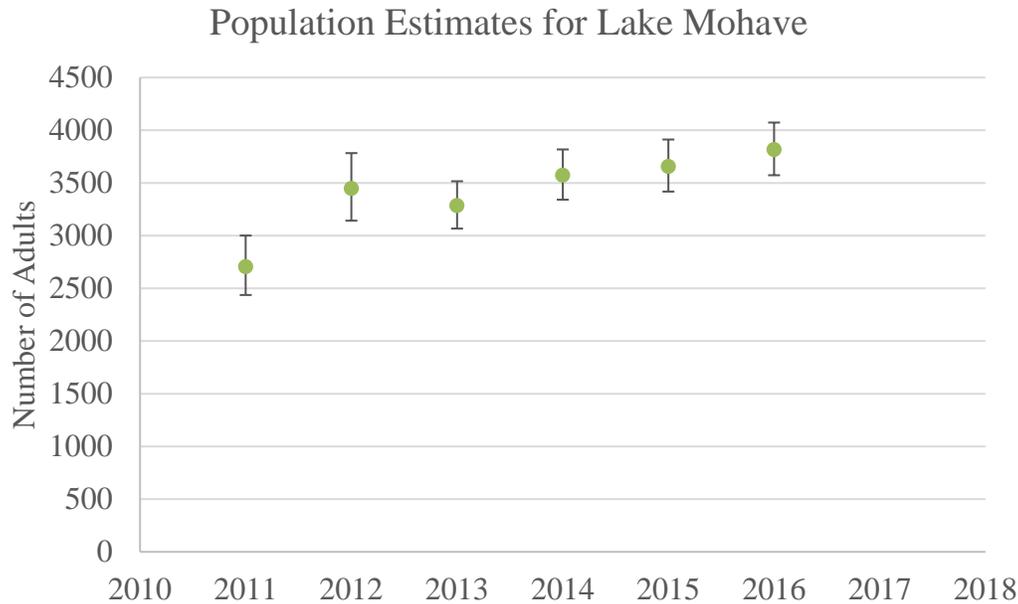


Figure 25. Razorback sucker population estimates for adults in Lake Mohave with error bars representing 95% confidence intervals from annual LCR MSCP surveys.

Spawning in nearshore areas possessing cobble and gravel substrates continues to occur, but there is very little evidence that wild larvae escape predation by nonnative fishes and recruit to juvenile sizes. A variety of nonnative fishes are known to prey on razorback sucker in Lake Mohave, with the larval stage being especially vulnerable (Kesner *et al.* 2016). Predation on larval razorback sucker by small centrarchids has been repeatedly observed during larval monitoring surveys, and consumption of eggs by channel catfish has also been observed. A recent study designed to detect razorback sucker DNA in nonnative fishes in Lake Mohave confirmed predation on larvae by all four centrarchid species that were sampled (Ehlo *et al.* 2017). Lake Mohave is a relatively clear and cool reservoir that lacks turbid inflow areas with submerged vegetative cover that are key spawning and juvenile habitats in Lake Mead. These habitats appear to be essential for natural recruitment.

The razorback sucker population in Lake Mohave represents the most genetically diverse but severely reduced wild population within the LCRB. Captive rearing of wild-spawned larvae allows managers to maintain genetic integrity, circumvent larval predation, and maintain the genetic variation of the population (Dowling *et al.* 2005). Currently, genetic diversity in Lake Mohave does not differ significantly between annual samples of stocked adult, larval, or wild razorback sucker (Dowling *et al.* 2013; Carson *et al.* 2016). Therefore, management efforts are achieving the goal of maintaining genetic integrity for razorback sucker in Lake Mohave.

Continued augmentation at present or increased levels of effort will be needed to stabilize the population at a size necessary to maintain genetic diversity. Transfer of adult razorback sucker in spawning condition to off-channel ponds adjacent to Lake Mohave would allow larvae and juveniles to reach maturity in predator-free environments (Minckley *et al.* 2003). To date, most studies have been restricted to ephemeral ponds, providing information on individual reproductive success. One permanent pond exists and progeny have recruited into the adult

population (Kesner *et al.* 2016). Expansion of this effort to create a series of off-channel habitats for exchange of adult razorback sucker with the reservoir has the potential to improve the efficiency of augmentation efforts at Lake Mohave.

5.3.2.3 Colorado River between Davis and Parker dams (Lake Havasu)

Razorback sucker are currently found from the inflow area of Lake Havasu up-river to the base of Davis Dam, representing one of the more successful reintroduction efforts within the LCRB (Wydoski and Lantow 2012), and demonstrating that recolonization of adult fish is possible after extirpation. The population of razorback sucker in Lake Havasu was created by stocking efforts after naturally-occurring razorback sucker had been extirpated from the area in 1986. More than 50,000 adults have been stocked in the reservoir and upstream portions of the Colorado River below Davis Dam since 2006, and the resultant population now numbers in the thousands (recent estimates range from approximately 2,500 to about 5,000 adult individuals (Figure 26) (Ehlo *et al.* 2015; Kesner *et al.* 2017). Trammel netting surveys and data from submersible PIT tag scanners have been used to monitor the population, but low numbers of recaptures have precluded precise abundance estimates. Survival rates of stocked razorback sucker appear to be similar to those at Lake Mohave, and vary with the size of the fish (> 350 mm TL have highest survival) and the date of stocking (Ehlo *et al.* 2015; Kesner *et al.* 2017).

Spawning activity has been documented, indicating that the population has the potential to provide larvae for hatchery propagation. This population has very limited potential for becoming a viable, self-sustaining population without recruitment, but could fulfill a role in serving as a refuge population maintained through augmentation, similar to the Lake Mohave population.

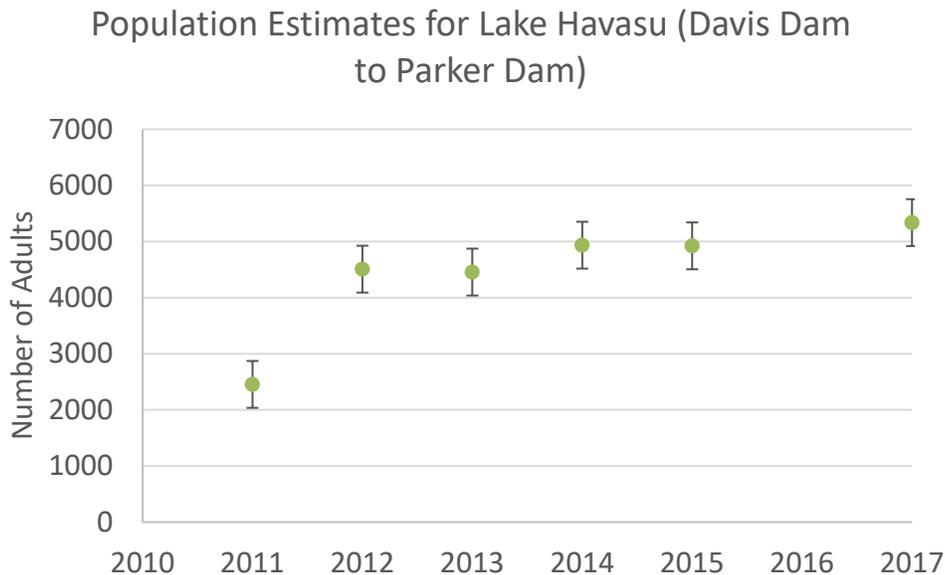


Figure 26. Razorback sucker population estimates of adults in lower Colorado River Reach 3 (Lake Havasu) using data from Kesner *et al.* (2017). Error bars represent 95% confidence intervals.

5.3.2.4 Colorado Mainstem below Parker Dam

Razorback sucker were historically abundant in reaches of the Colorado River below present-day Parker Dam, but the population rapidly declined and was nearly extirpated following the construction of mainstem dams and diversions. A few individuals were captured or observed in irrigation canals and reservoirs during the 1970s (W. L. Minckley 1983; Marsh and Minckley 1989).

More than 90,000 razorback sucker have been stocked between Parker and Imperial dams under the LCR MSCP between 2007 and 2017, 15,000 of which have been PIT-tagged (L. J. McCall *et al.* 2017). The PIT-tagged subset of razorback sucker were adult fish ranging from 275-640 mm TL; the stocking plan requires lengths >305 mm. Post-stocking survival of razorback sucker in this reach is poor; the largest fish stocked at >500 mm have an annual survival rate of 11% (Schooley *et al.* 2008). The primary cause of mortality is predation from piscivorous fish and avian predators. Tracking of released razorback sucker resulted in a population estimate of 216 adults (95% CI of 173, 271) in one backwater in the system (L. J. McCall *et al.* 2017). No estimates of in-river populations have been completed to date.

Senator Wash Reservoir is an off-channel reservoir in California used for pump-back water storage for irrigation located approximately two miles upstream from Imperial Dam where a substantial number of razorback sucker were entrained following its creation in 1966 (W. L. Minckley 1983). Razorback sucker are currently known to exist in Senator Wash Reservoir, due in large part to stocking efforts. In 2003-2004, populations were estimated to be 280 fish (95% CI of 212-400) (Kretschmann and Leslie 2006). Spawning behavior was observed but larvae were absent possibly due to high predation or reservoir operations, which may be drying eggs. Natural recruitment appears to be lacking (Kretschmann and Leslie 2006). Senator Wash Reservoir water elevations vary both diurnally and seasonally and the reservoir is home to a variety of nonnative fish, including flathead catfish, channel catfish, striped bass, threadfin shad *Dorosoma petenense*, largemouth bass, common carp, and various sunfish species (Kretschmann and Leslie 2006). Senator Wash Reservoir is not actively managed for razorback sucker, and currently there are no ongoing stocking efforts. At this time, the status of the razorback sucker population in Senator Wash Reservoir is unknown.

Although this section of river contains complex habitat (vegetation, backwaters and some turbidity), the prevalence of nonnative fishes in the portion of the Colorado River between Parker Dam and Imperial Dam are likely to prevent the establishment of a stable and viable population unless management actions are taken to create areas of favorable environmental conditions. River reaches downstream from Imperial Dam are even more unsuitable as razorback sucker habitat, because of extensive dewatering and channelization.

5.3.2.5 Additional areas

In the Gila River system, razorback sucker have been stocked in the Verde, Gila, and Salt rivers and their tributaries where the natural population had been extirpated (Hendrickson 1994). From 1991 to 2004, nearly 23,000 razorback sucker were stocked in the Salt and Verde rivers. The majority of stocked fish were smaller in size when compared to fish stocked into the mainstem Colorado River. Because only 285 of those fish were ever recaptured, survival of stocked fish is

assumed to be low (Hyatt 2004). In the Verde River, numerous fish have been recaptured, and survival of up to six years has been documented. In addition, ripe males were encountered in the Verde River, but no evidence of reproduction or recruitment was found (USFWS 2002). Razorback sucker were stocked into Fossil Creek (a Verde River tributary) during at least two periods with limited success and retention. Razorback sucker were stocked into Fossil Creek near Fossil Springs and near Irving, Arizona during October 1988. A few were observed during subsequent surveys in 1989 (Weedman *et al.* 2005). Some of the razorback sucker stocked in 1988 ended up in Stehr Lake where they persisted until they were removed during the salvage operation before the 2004 chemical treatment (Weedman *et al.* 2005). From 2008 to 2014, 4,076 razorback sucker were stocked into Fossil Creek (Love-Chezem *et al.* 2016). Larger individuals were stocked in 2008 (mean 295 mm TL), slightly smaller in 2009 (127-278 mm TL), and the 2,500 stocked in 2014 were largely <100 mm TL. During monitoring, only a few razorback sucker were observed in 2008 and 2009, and none were detected in 2010, 2011, 2013, 2014, or 2015 (Love-Chezem *et al.* 2016). Post-stocking downstream movements, along with Southwestern river otter *Lontra canadensis sonora* predation, suggests unfavorable habitat conditions within Fossil Creek for razorback sucker.

Survival rates in the Gila River basin appear to be low due to predation by nonnative fishes and altered habitat. Naturally occurring adult razorback sucker persisted in the Verde River until at least 1954, but young juveniles were last collected in the Gila River drainage in 1926 (Minckley 1983) and there has been no definitive evidence of reproduction or recruitment since that time. A few stocked individuals appear to have persisted for several years based on capture data from Horseshoe Reservoir, on the lower Verde River, and at Fossil Creek (Weedman *et al.* 2005). Had there been continued large scale stocking efforts in the Gila River it is not unreasonable to think that a similar situation that exists in the lower Colorado River below Hoover dam could exist in the Gila River basin. Because of the lack of survival of stocked fish and lack of recruitment, the areas in the Gila River basin have not been assessed as populations in this SSA.

5.3.2.6 Summary of Current Demographic Conditions for Lower Basin Populations

Table 13. Summary of lower basin demographic current condition for razorback sucker (high condition is represented by green, medium condition by yellow, low condition by orange and extirpated condition by red).

Population	Demographics					
	Adult population size (wild + stocked fish)	Spawning and larval presence	Recruitment	Dependence on stocking	Genetic integrity (inbreeding or hybridization)	Population stability (wild recruited adults)
Lake Mead (including Grand Canyon)	<ul style="list-style-type: none"> • 2017 Estimate: 421 (305-615) • 2014-2016 Estimates: Nets: 418 (327-559) Antennas: 589 (370-808) 	<ul style="list-style-type: none"> • Spawning occurs annually at multiple locations in Lake Mead proper (Echo Bay, Las Vegas Bay, Virgin/Muddy river inflows) and in Grand Canyon • Spawning occurs across a broad temporal period (February to May) • Larvae are found throughout Grand Canyon downstream of Havasu Creek, well dispersed (in spatial extent) but not documented in large numbers 	<ul style="list-style-type: none"> • Occurring annually in the lake • 59% of the fish caught in the lake are unmarked, indicating high levels of recruitment • Untagged adult fish have been caught in the Grand Canyon, but their origin is unknown • No juveniles have been documented in the canyon, but are periodically captured in Lake Mead. 	<ul style="list-style-type: none"> • Least augmented population in either basin • Fish are not commonly stocked in Lake Mead, small numbers of fish have been introduced to increase genetic diversity or to track specific fish movement • 70-80% survival in the lake 	<ul style="list-style-type: none"> • Less diverse than Lake Mohave and Lake Havasu populations • Genetic variation changes annually • Small subpopulations have potential for inbreeding • Hybridization with flannelmouth sucker documented in Grand Canyon and inflow area 	<ul style="list-style-type: none"> • Population is stable at low population levels, after a sharp decline occurred during the 1970's and 80s
Lake Mohave (including all river below Hoover dam) LCR MSCP Reach 2	<ul style="list-style-type: none"> • 2017 Estimates: Nets 1291 (531-3436)* Antennas 3815 (3573-4073) • 2016: Nets 1707 (603-3897)* Antennas 3572 (3341-3818) All repatriated individuals 	<ul style="list-style-type: none"> • Spawning and egg production occur annually in multiple locations throughout the system (known spawning locations are separated by 5, 8 and 30 miles) • 18,000-35,000 larvae collected annually throughout the spawning season for hatchery rearing and future repatriation. Spawning occurs across a broad temporal period (late Jan to May) 	<ul style="list-style-type: none"> • Undocumented, if occurring, expected to be minimal • Untagged adults in this reach are rare and are likely because of tag loss 	<ul style="list-style-type: none"> • Wild larvae are collected on an annual basis and raised in hatcheries, then returned to the river • 8,000 adults are repatriated annually (>400 mm) • 90% survival rates for adults at large in the reservoir for more than 2 years 	<ul style="list-style-type: none"> • Highest levels of genetic diversity documented for the species 	<ul style="list-style-type: none"> • Wild population is assumed extirpated; no wild adults have been documented. • Population is relatively stable in the presence of active augmentation • Populations have declined from historic highs, despite augmentation
Lake Havasu (below Davis dam to Parker dam) LCR MSCP Reach 3	<ul style="list-style-type: none"> • 2017 Estimate: 5337 (5043-5633) • Largest population in the LCRB All stocked individuals 	<ul style="list-style-type: none"> • Spawning and egg production occur annually in multiple locations throughout the system • Larvae are present 	<ul style="list-style-type: none"> • Undocumented, if occurring, expected to be minimal • Untagged adults in this reach are rare and are likely because of tag loss 	<ul style="list-style-type: none"> • 6,000-12,000 adult fish are stocked annually • Fish stocked at 350 mm have a survival rate of 10%, but event survival was as high as 58% with large fish released in small batches 	<ul style="list-style-type: none"> • Diversity similar to Lake Mohave • Hybridization may occur with flannelmouth sucker, but not documented at levels seen in Lake Mead 	<ul style="list-style-type: none"> • Wild population is assumed extirpated; no wild adults have been documented. • Population is stable and may be increasing, but consists of stocked/repatriated adults
Colorado Mainstem Below Parker Dam LCR MSCP Reaches 4 & 5	<ul style="list-style-type: none"> • Survival in these reaches is low; there are not enough fish to develop a population estimate 	<ul style="list-style-type: none"> • Low-level spawning and egg-production observed in backwater habitat at Senator Wash Reservoir and various backwaters in Blythe, California • Larval presence confirmed in backwater habitat in 2017 	<ul style="list-style-type: none"> • No evidence of natural recruitment • No untagged adults have been found in this reach 	<ul style="list-style-type: none"> • 6,000-12,000 fish per year are stocked from Bubbling Ponds (SNARRC) in this segment • Survival of stocked fish remains low, with largest stocked fish (>500 mm) surviving at rate of 11% 	<ul style="list-style-type: none"> • Genetic integrity is managed through stocking efforts, inbreeding has not been a concern 	<ul style="list-style-type: none"> • Population is not stable and only maintained by stocking

5.4 Current Species Viability

As noted in the introduction, species viability is related to the species' ability to withstand stochasticity (resiliency), the ability to withstand catastrophic events by spreading the risk among multiple populations (redundancy) and the ability to adapt to changing environmental conditions (representation). An assessment of each of three R's (resiliency, redundancy and representation) provides an assessment of the species' ability to persist in the wild.

5.4.1 Resiliency

Razorback sucker are adapted to a wide variety of ecological conditions found throughout the Colorado River basin. Populations in the upper basin are primarily lotic; populations in the lower basin occupy both lotic reaches and reservoirs created for water storage and management in the past 50-70 years. Razorback sucker prefer cobble or rocky substrate for spawning, but have been documented to clear sediment from cobble and even spawn successfully over clay beds. Juveniles and adults have access to appropriate habitat throughout the system ranging from backwaters and floodplains to deep and slow moving pools, however nonnative fishes are frequently found in such habitats as well. The species is tolerant of wide-ranging temperatures, high turbidity and salinity, low dissolved oxygen and wide ranging flow conditions. Razorback sucker consume a variety of food items, based on their occupied habitat. Razorback sucker typically become sexually mature between 3-4 years, and can live for more than 40 years. Once adults have recruited into the system, they can persist for many years and spawn multiple times. Recruitment continues to be functionally nonexistent across the basin primarily because of a persistent presence of nonnative predators and lack of rearing habitat, compromising resiliency of most populations.

When both habitat and demographic conditions for each population are averaged to represent resiliency, all populations fell into the medium (2) condition with the exception of the Colorado River below Parker Dam, which resulted in a low (1) condition (Table 14).

Table 14. Summary of current condition, averaged with all species needs (habitat and demographic factors) and demographic factors only. On a scale of 0 (extirpated) to 3 (high condition) an average value of 0-0.75 represents extirpated condition, 0.76-1.5 is low condition, 1.51-2.25 is medium condition and 2.26-3 is high condition. The limiting demographic need column provides the lowest demographic categorization per population to show limiting factors.

Population	Average of Habitat and Demographic Needs	Average of Demographic Needs Only	Limiting Demographic Need
Green River subbasin	2.2	1.8	1
Colorado River subbasin	1.8	1.3	0
San Juan River subbasin	1.8	1.3	0
Lake Powell	2.0	1.5	1
Lake Mead	2.2	2.5	1
Lake Mohave	1.7	1.5	0
Lake Havasu	1.7	1.3	0
Colorado River below Parker Dam	1.1	0.5	0

When only demographic conditions for each population are averaged to represent resiliency, one population is in high condition (3), one population is in medium condition (2), five are in low condition (1) and one is in extirpated condition (0) (Table 14 and Figure 27). As seen in the condition category tables above (Table 4 and Table 5), different definitions were developed to categorize each aspect of resiliency on a high to extirpated scale. In the following section, we average the conditions across the categories to provide an overall assessment of resiliency. We acknowledge this is not a scientific assessment, but an attempt to develop a tool that can easily communicate the differences among populations.

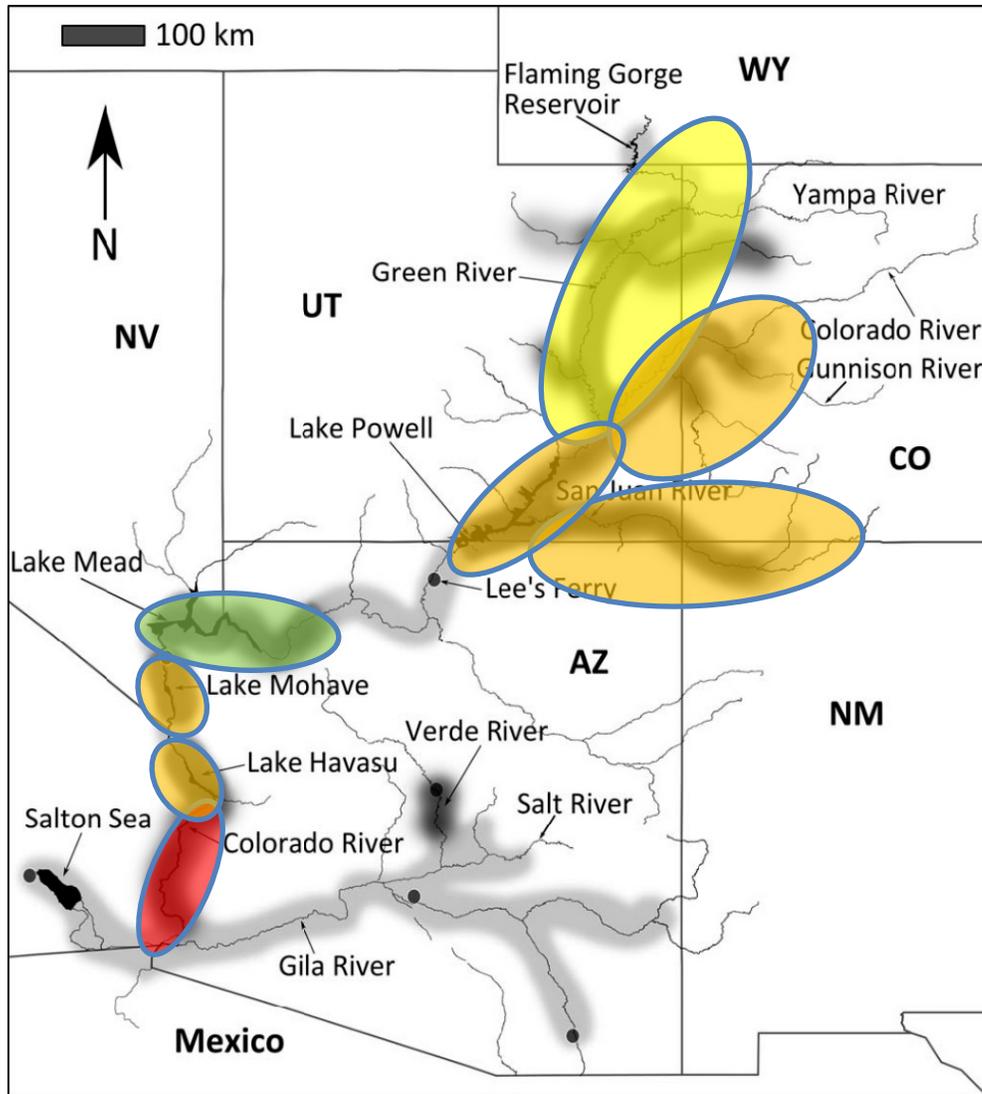


Figure 27. Historical (light gray) and current (dark gray) distribution of the razorback sucker in the Colorado River with different populations indicated by ellipses with colors representing an average of current condition of demographics. High condition is indicated by green (average score of 2.26-3), medium condition is indicated by yellow (1.51-2.25), low condition is indicated by orange (0.76-1.5), and extirpated condition is indicated by red (0-0.75).

In the upper basin, juveniles have been captured at very low levels in some years. The management of floodplain wetlands in the Green River has shown that juvenile recruitment is possible when large-bodied nonnative fishes are excluded from juvenile habitat and habitat conditions are maintained, which increases the resiliency of this population. Accessibility of floodplain habitats to larvae has been improved through management of peak dam releases timed to coincide with larval drift. Managing floodplains to increase juvenile recruitment is labor intensive, including filling and draining the wetlands, excluding nonnative fish, managing cattails and other vegetation and maintaining water volume and quality. Adult recruitment has only been documented in Lake Mead, but evidence suggests that it may also be occurring to some extent in Lake Powell. In the lower basin populations, nonnative fishes are a dominant presence preventing detectable recruitment in all populations except Lake Mead.

Although the species is resilient to a variety of environmental conditions, nonnative predation is preventing significant recruitment from occurring in most populations, dramatically reducing the resiliency of the species. Loss of floodplain habitat and connectivity is also limiting populations in the upper basin. The population in Lake Mead is currently the only population with natural ongoing recruitment, and has shown a high degree of resiliency by persisting despite a heavy nonnative fish presence. However, the Lake Mead population size is persistently low which presents a high risk for failure. Lake Mohave's population relies on collection of larvae, growth in off-channel predator-free ponds and reestablishment of adult fish to avoid predation of juveniles in areas dominated by nonnative fish. More traditional stocking techniques have been successful in maintaining the population in Lake Havasu, but populations have not established below Parker Dam. Currently, all populations (except Lake Mead) are dependent on active stocking because of a lack of recruitment and self-sustainability. Without continued management actions (primarily stocking), the resiliency of all populations other than Lake Mead would likely be in an extirpated condition.

5.4.2 Redundancy

Razorback sucker are present in populations spanning the entire Colorado River basin, exhibiting a high degree of redundancy. The species is expected to survive localized, and even regional catastrophic events such as fire and drought. Despite the presence of major mainstem dams, razorback sucker occupy much of their historic habitat and are distributed across six states in both rivers and reservoirs. However, current population densities are lower than have been documented historically. The four upper basin populations are connected and individuals have transitioned between them (with the exception of fish moving into the San Juan). Razorback sucker in the Green and Colorado subbasins use a variety of tributaries, either year round or seasonally (in some cases for spawning). Individuals have been documented to move hundreds of miles through multiple upper basin populations. Documented movement data strongly suggests that individuals from nearby, unaffected reach would quickly recolonize local extirpations. Redundancy of populations is dependent on stocking.

Lake Mead, Lake Mohave and the Colorado River between Davis Dam and Parker Dam (Lake Havasu) span hundreds of miles and have high internal redundancy as well – meaning fish are not concentrated in a single area but instead reside in several locations throughout each reservoir and associated inflows. As noted above, the lower basin populations exist in locations dominated

by large-bodied nonnative predators, which puts them at some risk. If stocking was discontinued, we expect populations would dwindle and disappear from Lake Mohave and the Colorado River between Davis Dam and Parker Dam (Lake Havasu). The Colorado River downstream of Parker Dam contributes little to redundancy despite active stocking efforts.

5.4.3 Representation

Razorback sucker have shown a high degree of plasticity in their ability to inhabit both lotic and lentic habitats. After populations were dramatically reduced in the upper basin, stocked individuals have displayed the ability to migrate, presumably for spawning purposes. Genetics of upper and lower basin populations have been assessed; results reveal healthy amounts of diversity and little reason for related concerns. Lower basin populations, especially in Lake Mohave, exhibit higher genetic diversity and less relatedness than upper basin populations (Dowling *et al.* 2012). For this reason upper basin broodstock managers incorporated a relatively small amount of lower basin genetics. Upper basin broodstock have always been used for upper basin augmentation efforts.

Some hybridization occurs with other native and nonnative suckers, but currently only at low levels. Genetic representation both within and among populations is thought sufficient because it is being managed in hatcheries. Genetic adaptability will remain low as long as population level recruitment and self-sustainment is missing, and populations are dependent on stocking. Natural recruitment (and selection), currently lacking in most populations, will be a necessary component of genetic adaptability in the future.

6 FUTURE CONDITION AND VIABILITY

6.1 Expert Elicitation

6.1.1 Assessment of Multiple Generations

We used a Delphi process to quantify factors most likely to affect razorback sucker in the future, including risk and conservation factors in the analysis. The Delphi process draws on a panel of experts to forecast probable outcomes using a series of questionnaires and a structured feedback process (Dalkey and Helmer 1963; Linstone and Turoff 1975; Hsu and Sandford 2007). The Delphi technique has been applied successfully to a variety of environmental analysis contexts for more than 50 years. Typically, the process involves at least two rounds of scoring by the expert panel with group feedback provided between scoring rounds. The process used here (full methods and results in Appendix A) involved three rounds of scoring to identify both risks and conservation actions for the razorback sucker across the populations in both upper and lower basins. In the first Delphi round, participants were asked to rank and weight a list of factors and subfactors potentially influencing the near-term viability of razorback sucker (within the next 30 years). In the second round, each participant was sent a customized report indicating how their weightings compared with the group response. The report flagged any individual's factor and subfactor weightings that were higher or lower than the group average by one standard deviation. Each participant was asked to comment on their higher and lower weightings, as well as to provide any other observations that they wanted to share. In the third round, participants were asked to consider the comments and reweight each factor and subfactor (they could keep the existing weight or select a higher or lower weight based on their reaction to comments).

For the purpose of this assessment, a period of approximately 9 years into the future was considered one-generation time for the species. Generation time (GT) is the average interval of time between the birth of parents and the birth of their offspring, or the average time for a population to increase by a factor equal to the net reproductive rate (Seber 1982; M. Gilpin 1993). It was computed as:

$$GT = \text{age}_{sSM} + (1/d)$$

where: age_{sSM} = average age at sexual maturity, and
 d = death rate.

Generation time for the razorback sucker was computed from an average age of sexual maturity of approximately 4 years and an annual adult mortality or death rate (based on the wild Lake Mead fish survival rate as described by Mohn *et al.* 2015) of $1 - 0.80 = 0.20$; i.e., $4 + (1/0.20) = 4 + 5 = 9$ years.

6.1.2 Assessment over 30 Years

For the purpose of this SSA, USFWS assesses the future time frame as 30 years into the future, representing 3+ generations. The USFWS finds this length of time to be biologically meaningful but also foreseeable as there is sufficient uncertainty regarding impacts of changes in streamflow,

potential modifications to water temperature, nonnative fish predation and competition, and ongoing human demands for water.

Participants were asked to rank the risk and conservation actions most impactful to razorback sucker over the next 30 years (approximately three generation times). Participants ranked eight major categories of factors in perceived order of importance and assigned each factor a weight out of 100 total points. They were then asked how they thought risks and conservation measures would change beyond that (30-100 years).

The future condition of razorback sucker habitat and species demographics are intrinsically linked to stream flow and water temperature, both of which are affected by human water demand and climate change and nonnative species. Participants weighted nonnative predation as the most influential factor over the next 30 years, followed closely by two habitat-influencing factors: flow regime and water management (Figure 28). Comparison of the error bars for each factor illustrate that there were no significant changes in mean weighting from Round 1 to Round 3, which was also confirmed by ANOVA tests (ANOVA, $p < 0.05$ for all factors). In addition, there were no changes in the rank order of mean weights between scoring rounds.

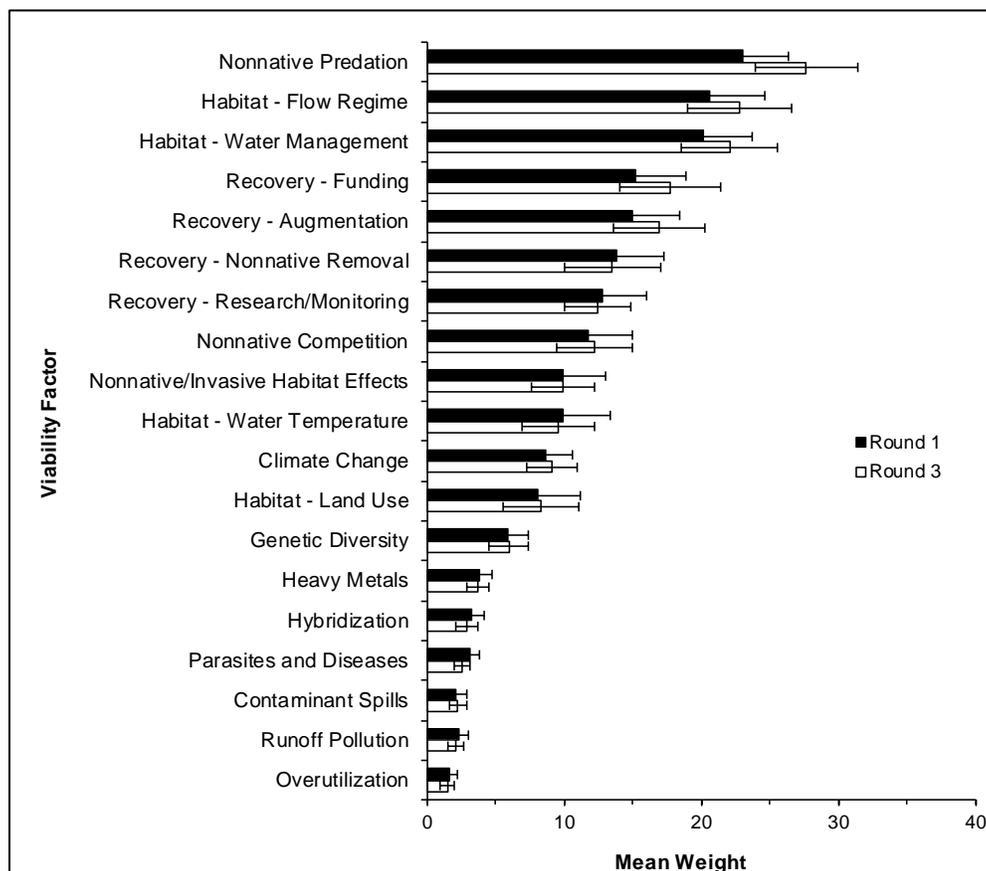


Figure 28. Mean weights of importance (out of 100 total points) assigned to factors potentially influencing viability of razorback sucker during the next 30 years (± 2 Standard Errors) as assessed by the Delphi participants

The most noticeable change was an increase in weights assigned to the five top-ranked factors, with nonnative predation receiving the largest increase in weight. However, variability in

weights assigned to the most influential factors remained high in Round 3, as indicated by measures of variation remaining higher for the top-weighted factors compared with the lower-weighted factors. Statistics indicating variability in weightings (the interquartile range and the minimum and maximum weights) suggest that there were higher levels of agreement regarding the less influential factors. In particular, the interquartile range was less than 10 for genetic factors (genetic diversity and hybridization), pollutant factors (heavy metals, runoff pollution, contaminant spills), parasites and diseases, and overutilization, indicating that at least half of the participants weighted these factors within 10 points of one another.

Based on a consideration of post hoc comparisons (Table 15), the factors were grouped into four tiers of influence in the following manner:

- In the top tier of influence are the three factors that the group weighted highest: nonnative predation and the top two habitat-influencing factors, flow regime and water management (shown as Shared Group A in Table 15). Mean weights for these three factors all exceeded 20 in the Round 3 results.
- The second tier primarily includes conservation and recovery efforts: program funding, augmentation, nonnative removal, and research and monitoring. The group’s mean weights for these factors ranged from a high of 17 to a low of 12 (shown as Shared Group C in Table 15). Nonnative competition was also included with this tier at the lower end of the range with a mean weight of 12.17.
- The third tier consists of secondary factors that are related to the top tier of factors; these are habitat-quality influencing factors with mean weights between 10 and 3 (shown as Shared Group E in Table 15). These factors include habitat effects of nonnatives, water temperature, climate change, land use, and heavy metals. Genetic diversity is also grouped in this tier.
- In the fourth tier are the factors that the group assessed as being the non-influential factors, at least at the species scale: hybridization, parasites and diseases, contaminant spills, runoff pollution, and overutilization. These factors all had mean weights less than 3 (shown as Shared Group H in Table 15). Some participants thought that some of these factors were being underrated by the group or that these factors may have effects for some localized populations, such as hybridization, runoff pollution, and risk of contaminant spills.

Table 15. Post-hoc, all-pairwise comparison analysis based on Tukey’s honest significant differences test, Round 3 group weights.

Factor	Mean Weight	Homogeneous Groups^{a*}	Shared Group^a
Nonnative Predation	27.64	A	A
Habitat - Flow Regime	22.77	AB	A
Habitat - Water Management	22.04	AB	A
Recovery – Funding	17.68	BC	C

Recovery – Augmentation	16.92	BC	C
Recovery - Nonnative Removal	13.52	CD	C
Recovery - Research/Monitoring	12.47	CD	C
Nonnative Competition	12.17	CD	C
Nonnative/Invasive Habitat Effects	9.85	DE	E
Habitat - Water Temperature	9.53	DE	E
Climate Change	9.09	DEF	E
Habitat - Land Use	8.28	DEFG	E
Genetic Diversity	5.94	EFGH	E
Heavy Metals	3.67	EFGH	E
Hybridization	2.94	FGH	H
Parasites and Diseases	2.55	GH	H
Contaminant Spills	2.22	GH	H
Runoff Pollution	2.07	GH	H
Overutilization	1.45	H	H

^a Letters denote groupings of factors in the post-hoc test, with significantly different scores indicated by each letter.

Participants were also asked to rate factors and subfactors by basins on a 1–5 scale. A sensitivity analysis was completed to compare the influences between the upper and lower basin. The relative weight of each factor (Figure 29) indicates which basin is predicted to be more impacted by that risk. If participants made no distinction between the UCRB and LCRB for a given factor, then that factor would have a mean relative weight of zero. In many cases, the error bar overlaps zero, reflecting variability in ratings among participants.

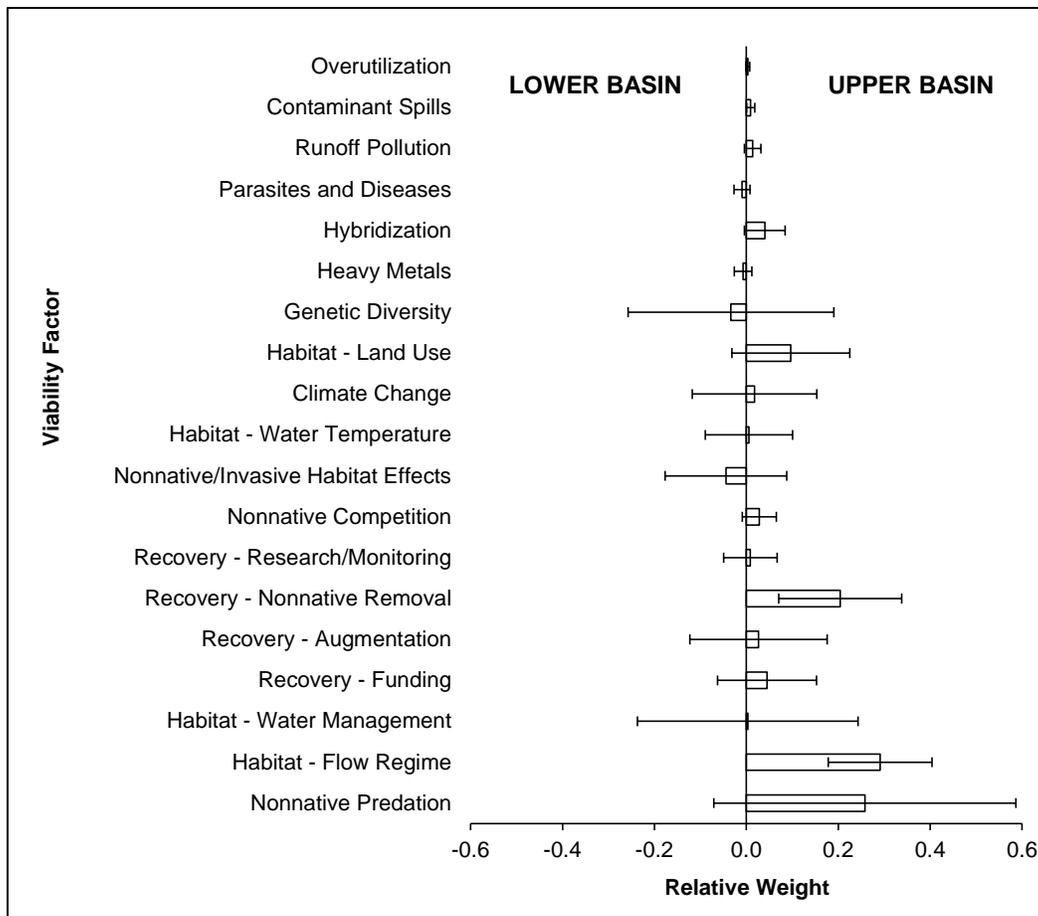


Figure 29. Mean relative weight of factors for the continued Razorback Sucker population viability in the UCRB and LCRB Round 3 (± 2 Standard Errors), as determined by the expert panel (± 2 Standard Errors). Wider bars indicate greater differences in impact between the upper and lower basin.

Looking at all of the factors (Figure 29), the only ones that do not have error bars overlapping zero are flow regime and nonnative removal; thus, participants rated these factors as being more influential in the UCRB. Factors that were perceived as a little more influential in the LCRB were habitat effects of nonnative/invasive species, genetic diversity, heavy metals, and parasites and diseases, but all have standard errors that cross zero.

6.1.3 Longer-Term Assessment (30-100 years)

Participants were asked to rate whether they thought that major categories of factors would become more or less influential 30–100 years in the future in relation to over the next 30 years. Participants were asked to rate the major factor categories (not subcategories) on a 1–5 scale with 1 representing “less influential,” 3 representing “same influence” and 5 representing “more influential.” As with the previous assessments, participants rated these factors in Round 1, provided comments regarding their ratings in Round 2, and then had the opportunity to update their ratings in Round 3 based on review of the comments provided by others. As is evident from the error bars in Figure 30, variability decreased for all of the long-term factor ratings in Round 3 and the group averages shifted slightly. None of the factor averages changed mean ranked order from Round 1 to Round 3.

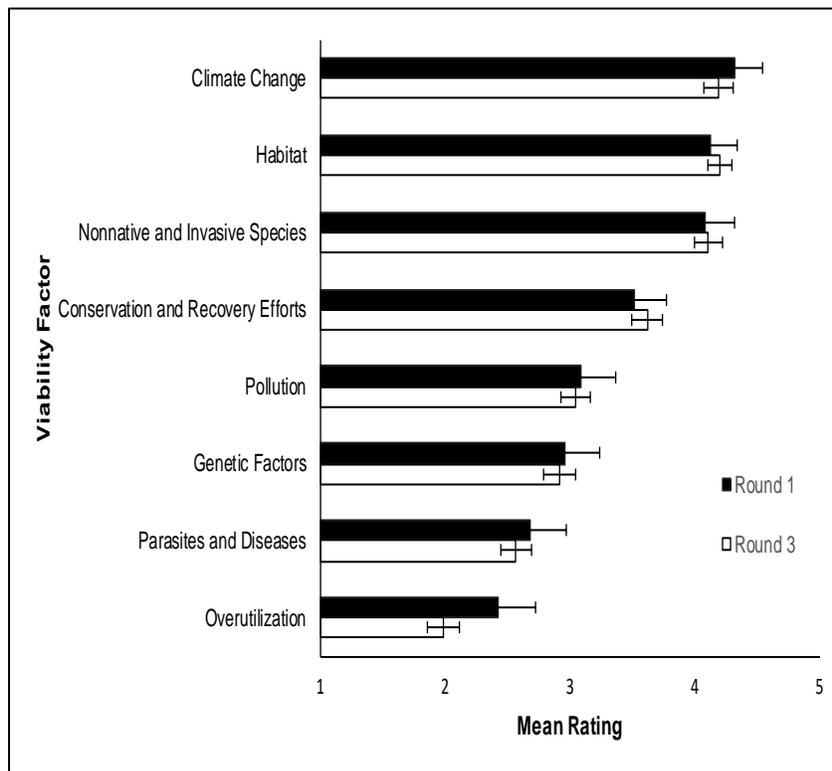


Figure 30. Mean ratings of expected change in influence on viability in 30–100 years on a 1–5 scale with 1 representing “less influential,” 3 representing “same influence,” and 5 representing “more influential” (± 2 Standard Errors).) over the longer period as assessed by the Delphi participants.

Participants expected climate change to become more influential in the 30–100 year period than during the next 30 years. Participants rated habitat and nonnative species as highly influential in the near term and expected these factors to become more influential in the long term.

The mean rating for climate change decreased slightly from Round 1 to Round 3 (Figure 30). In Round 2, participants were asked to provide comments for any of their ratings that were one standard deviation higher or lower than the group’s average rating. Those who did not rate climate change as increasingly influential in the 30–100 year period (a rating of 3) explained their rating based on greater than expected resiliency and adaptability of razorback sucker at the present time, the broad geographic range of the species, and its apparent adaptability to historic climate variability and stochastic events through its evolutionary history. Others thought climate change may have some positive effects such as providing warmer water where it is presently too cold or possibly improving habitat as a result of earlier spring flows in some locations. While there was a slight decrease in the group’s average rating of climate change in Round 3 (mean = 4.2, standard deviation = 0.7), the majority of participants continued to rate climate change as becoming more influential 30–100 years in the future.

Participants also expected conservation and recovery efforts to continue to influence long-term viability, having the same or an even greater influence beyond 30 years from the present. Thus, participants were not particularly optimistic that razorback sucker would become independently viable in the long term, with wild recruitment being referenced as the necessary element to

ensure viability. Pollution and genetic factors were expected to have the same long-term potential influence as these factors would have in the nearer term. Parasites and diseases and overutilization were not expected to be longer-term influences and would possibly become even less influential in the 30–100 year time frame as rated by the participants.

This assessment of the 100-year period is used in a limited manner in this SSA because of the difficulty in predicting conditions over that time frame. It is used only in providing the Science Team’s probability assessment of the various scenarios over a longer time frame but is not assessed specifically in future scenarios.

6.2 Future Environmental Condition

Based on the Delphi process, the Science Team developed a range of future scenarios, limited in scope to the most influential risks and conservation actions (Figure 31). The goal of scenario development was to take the most influential factors and predict how they are likely to affect razorback sucker populations over the next 30 years. The scenarios developed by the Science Team were based on a probable range of conditions in the top two tiers of influential factors from the Delphi process (Appendix B). This process was qualitative in nature and is meant to be a summary of their best scientific judgement.

Over the past 30 years, management actions have increased and/or supported populations across the Colorado River basin and have, in many cases, developed the populations currently in place through active intervention. Because of the reliance of this species on continued management, the scenarios represent different levels of management action or intervention in the system and their subsequent effect on the populations based on the effectiveness of those management actions. All scenarios assume higher water temperatures and lower water availability in the system as a whole based on the research presented in section 4.1.

- Scenario 1 – Scenario 1 represents a dramatic decrease in conservation and recovery actions resulting from the elimination or reduction of programs authorized to carry out such actions or the funding that supports them. This scenario assumes an elimination of some active recovery and adaptive management actions, and a reduction in voluntary management actions for the species, such that many actions are no longer in place to mitigate future conditions including decreased water availability, future water development, or nonnative fish pressures.
 - LCR MSCP funding and adaptive management actions continue through 2055 as directed in the funding legislation. GCDAMP funding and management actions continue indefinitely.
 - Conservation actions codified under binding agreements (e.g. National Environmental Policy Act (NEPA), Section 7) would continue. For example, instream flows would be legally protected as they are today (e.g. Record of Decisions (ROD) and PBOs remain in effect); volunteer water management actions would likely cease.
 - State wildlife management actions would continue at self-directed levels. Mechanical control of nonnatives would likely cease or be severely reduced; monitoring would diminish to population monitoring that occurs at the state level only.

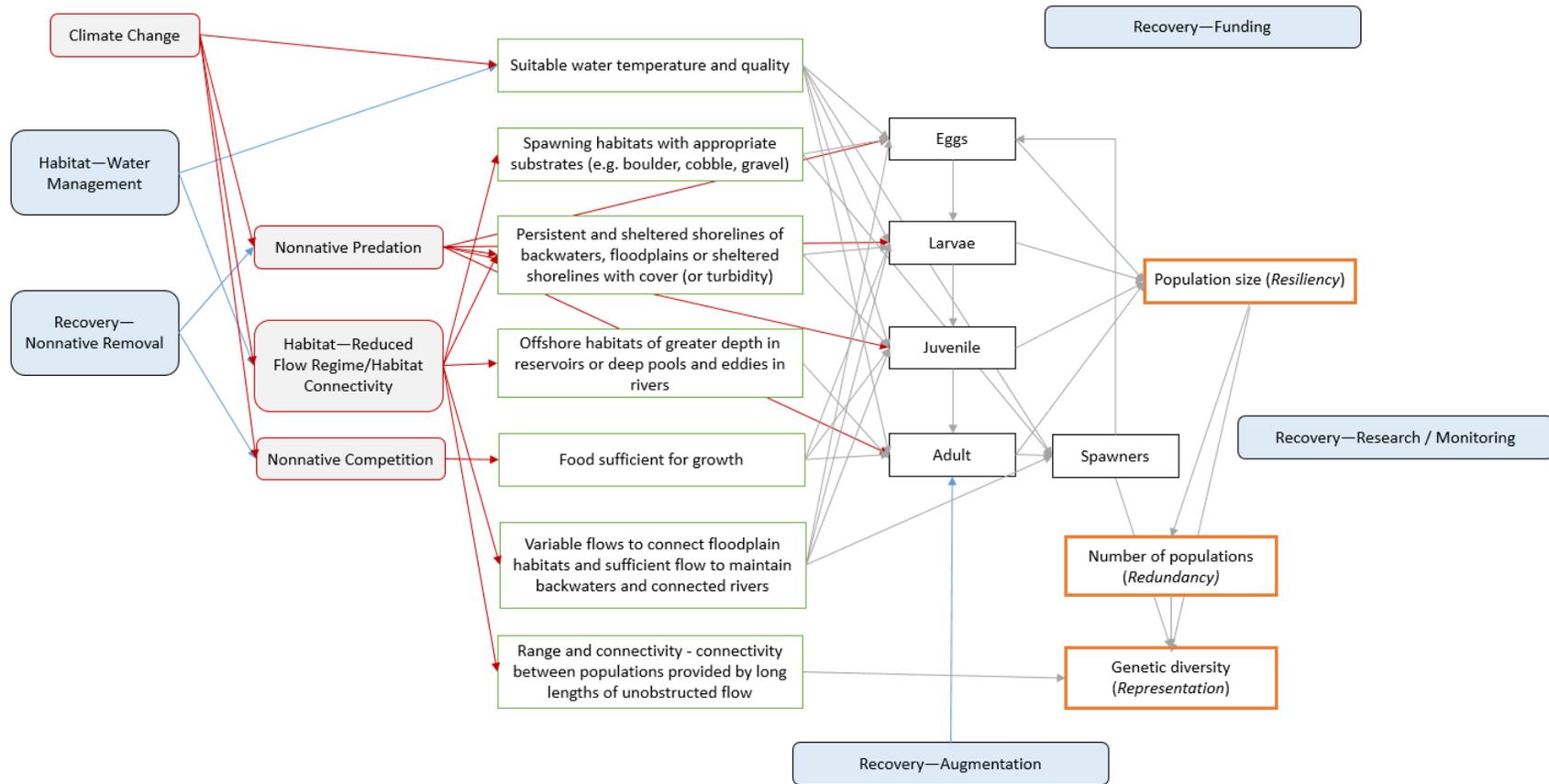


Figure 31. Flowchart of risks (gray with red outline) and management actions (blue rectangle) on razorback sucker individual and population needs (green outline) and their subsequent effects on the life stages (black outline) and 3Rs (orange outline), limited to tier 1 and 2 effects and those most likely to increase influence in future years. No lines are present connecting recovery program funding and research/monitoring to specific life stages as they have overarching effects on the entire system.

- Screens & fish passages would likely not be maintained, wetlands & backwaters would not be managed or maintained for recruitment, and augmentation would dramatically diminish in the upper basin, but would continue in accordance with LCR MSCP guidance.
- Scenario 2 – Recovery actions continue at levels thought to be beneficial to the species as are currently in place, but augmentation efforts are less effective than is currently observed, resulting in a reduction in survival of stocked fish. Overall effectiveness of recovery actions is below current levels.
 - In addition to minimum actions required under Scenario 1, additional proactive and adaptive stakeholder agencies management practices occur into the future for the species.
 - Current and likely future actions include: mechanical removal of nonnative fishes in the upper basin, monitoring and research across populations, mandated and voluntary flow efforts to provide habitat and allow connection to nursery habitats actively managed by the programs in the upper basin, development and maintenance of predator free backwaters in the lower basin, maintenance of irrigation canal screens and fish passages, managing nonnative vegetation to restore habitat and active augmentation (i.e. stocking or reintroduction).
 - A decrease in effectiveness could be caused by a disease or parasite in the hatchery system or the establishment of a new predator in the system, reducing the survival of stocked fish (e.g. flathead catfish in the upper basin, or lack of concern about northern pike and smallmouth bass during the early years of the program).
 - Some participants assumed a negative management feedback loop would begin (e.g. if populations started to die off and were unable to be restored through augmentation that other efforts, other actions specifically related to habitat management may decrease as a result).
- Scenario 3 – Recovery actions continue at levels thought to be beneficial to the species (includes legally mandated actions plus adaptive and voluntary efforts currently in place), and are effective at reducing some threats. This scenario represents continuation of the status quo, both in terms of the current assemblage of recovery activities and their current levels of effectiveness.
 - In addition to minimum actions required under Scenario 1, additional proactive and adaptive stakeholder agencies management practices occur into the future for the species.
 - Current and likely future actions include all listed in Scenario 2
- Scenario 4 – Recovery actions continue at levels thought to be beneficial to the species (includes legally mandated actions plus adaptive and voluntary efforts currently in place) and are effective at reducing threats to a level supporting recruitment, which offsets some adult mortality. This scenario assumes reduction of current stressor(s) affecting populations.
 - In addition to minimum actions required under Scenario 1, additional proactive and adaptive management practices occur into the future for the species.
 - Current and likely future actions include all listed under Scenario 2.

- Assumes a reduction in the pressure from nonnative predation, competition and/or habitat effects through either nonnative removal or establishment of predator free habitat. Management thought to repeat/increase floodplain habitat, successfully exclude predators from habitat or potentially remove large barriers to connectivity such as the San Juan Waterfall is incorporated.
 - Stocking assumed to decline and then possibly ceases because of wild populations in some places.
- Scenario 5 – Recovery actions support wild populations (includes legally mandated actions plus adaptive and voluntary efforts currently in place), and are effective at reducing most threats in the system. This scenario assumes the addition of more effective techniques to suppress effects of nonnative fishes, resulting in increased numbers of fish and enhancement of rearing habitats and their management such that recruitment completely sustains the viable populations without the need for augmentation.
 - In addition to minimum actions required under Scenario 1, additional proactive and adaptive stakeholder agencies management practices occur into the future for the species as needed.
 - Current and likely actions include all listed under Scenario 2 with the addition of new tools currently unavailable.
 - Assumes elimination of the pressure from nonnative predation, competition and/or habitat effects through novel techniques (e.g. genetic or biological) dramatically reducing nonnative populations in razorback sucker habitat.
 - Stocking assumed to decline and then possibly ceases because of wild populations in some places.
 - Mechanical removal of nonnative species ceases as other techniques are more successful.

The Science Team for scenario development were then asked to individually assess the effects of each of the scenarios on each of the species' habitat and demographic needs as explored in Chapter 3 and their assessment of current condition in Chapter 5. Each participant was asked if the current condition was likely to remain the same, increase by one condition category, increase by two or more condition categories, decrease by one category or decrease by two or more condition categories based on the condition category tables presented in Chapter 5 over the 30-year period. The results were averaged for each condition in each population and then averaged overall to provide a single resiliency prediction for each population. During the discussion about condition categories, the group noted that the condition category tables did not necessarily represent the entire range of environmental conditions from pre-anthropogenic effects to completely lacking ecological function, but instead represented a likely range of conditions. Therefore, during the future condition discussions, the results were allowed to incorporate values higher or lower than the categories in the condition category tables. The results of that assessment were compiled and presented here.

6.2.1 Scenario 1

Scenario 1 represents a dramatic decrease in conservation actions represented by the elimination of activities and programs not mandated by law. The upper basin programs (i.e. UCREFRP and

SJRIP) are currently operating under cooperative agreements through 2023 and are funded through 2019. Program partners are negotiating the extension of funding and work managed by the programs, but a future without the UCRB programs must be considered as a possibility.

The greatest threats from Scenario 1 in the upper basin would stem from increasing temperatures and lower flows with no flow management, coupled with unchecked nonnative predation and competition, and discontinuing stocking. Little would likely change in the lower basin as most actions are conservation-oriented (i.e. recovery is not the goal) and mandated through the LCR MSCP (Figure 32). As a Habitat Conservation Plan (HCP), the LCR MSCP program provides ESA compliance to any and all Federal and non-Federal actions, including flow and hydropower facilities, occurring in the study area over a 50-year time frame. A ROD published in 2005 authorizes implementation of the HCP through 2055. The (U.S. Department of Interior 2005). GCDAMP authorizations continue indefinitely.

Green River Subbasin - The Green River subbasin is home to the largest known population of razorback sucker in the Colorado River Basin. Although the more than 30,000 razorback sucker estimated to inhabit the basin are primarily hatchery fish, they actively spawn and produce larvae at several historic, and new, spawning bars on an annual basis. Recent flow recommendations out of Flaming Gorge have allowed for the development of managed wetlands that have produced young-of-year razorback sucker annually (operating under the biologically-based LTSP. Nonnative fishes have established resident populations that prey upon and compete with native fish. The primary threat comes from smallmouth bass, northern pike and walleye.

Stream flow would decrease and return to less natural flow regimes without active management because flows are heavily impacted by upstream reservoir operations. Operation of Flaming Gorge would continue under the 2006 ROD preventing catastrophic low flows, but flows on major tributaries like the White, Yampa and Duchesne would likely be in jeopardy. Increases in water demand or decreases in water supply could limit options available for the operation of Flaming Gorge Dam to primarily drier hydrologic conditions (i.e. reduce the number of years in which floodplain connections could be made), which would improve conditions for smallmouth bass in razorback sucker habitats.

The risk from predation/competition by nonnative fishes would increase substantially as smallmouth bass would be advantaged by lower flow conditions and subsequent warming of water, and would not be actively managed through nonnative removal programs. Habitat conditions are likely to decrease primarily because of less flow management and lack of floodplain access. Adults currently in the system would likely survive for a number of years, but would not be replaced by new individuals after stocking ceased, causing dramatic population declines, and reach extirpated condition over 30 years.

Colorado River Subbasin - The Colorado River subbasin population currently consists of about 8,000 adult razorback sucker. Although small numbers of fish are caught untagged, the vast majority of fish in the population are hatchery produced and recruitment is assumed rare. Nonnative fish populations are present throughout the system, with resident populations of smallmouth bass in both the main channel and tributaries.

Reduced stream flows caused by reduced snowpack would not be actively managed and would result in low water conditions, especially in late summer. Reclamation's ROD at the Aspinall Unit and other long-term flow commitments protect against extreme low flows, but voluntary flow management in the upper Colorado River could diminish, especially in the '15 mile reach' where spawning is prevalent. River temperature is expected to warm, but the direct effects on razorback sucker is not expected to be measureable. The food supply is reliable and is expected to continue to be suitable into the future, but may be impacted by drying conditions.

The risk from predation/competition by nonnative fishes would increase substantially as smallmouth bass would be advantaged by lower flow conditions and subsequent warming of water, and would not be actively managed through nonnative removal programs. The risk for increase and expansion of nonnative fishes is greatest in consecutive years of low flow, which would occur more often without management. Under this scenario, the Colorado River subbasin razorback sucker population would likely reach extirpated condition within 30 years.

San Juan Subbasin - The San Juan subbasin has a resident razorback sucker population of about 3,000 adults, developed through stocking efforts. Nonnative predation is not as prevalent as in the Colorado or Green river subbasins, with only channel catfish posing a threat. Razorback sucker recruitment remains poor to non-existent in the system. Researchers are exploring possible causes of recruitment failure.

Navajo Dam is the major water storage project in the basin and is required to release flows in accordance with the Biological Opinion (BO) for that system as long as water is present. If future climate predictions are accurate, this may be one of the areas hardest hit by reduced snowpack and drier conditions, severely limiting water availability in the basin. If the SJRIP were to cease management actions, the razorback sucker population would likely decline quickly and reach extirpated condition within 30 years.

Lake Powell - The status of the Lake Powell razorback sucker population is still very much in question as few studies have been completed to assess the population, and the studies that have been completed are usually focused on specific areas around the lake and not the lake in its entirety. There is a razorback sucker population resident to Lake Powell that consists of fish stocked in the Green, Colorado and San Juan subbasins as well as a substantial number of fish of unknown origin.

Lake Powell is not currently managed for razorback sucker, so the absence of management actions are not likely to have any effect on the habitat, however, reduced or eliminated stockings may reduce this population significantly. Increasing temperatures and decreased water availability could decrease lake levels, opening different habitat for razorback sucker. It is difficult to ascertain whether this would have a positive or negative benefit on the species. Although stocking does not occur in Lake Powell proper, many of the fish in this population originated through stocking in the upper basins, which indicates that a lack of stocking in those areas may lead to decreased population levels in the lake, causing extirpated conditions in 30 years.

Lake Mead (including Grand Canyon) – Lake Mead currently contains the only razorback sucker population in the system that is recruiting. Although population levels are low (around 500 individuals), razorback sucker are not augmented in Lake Mead and are not supported by management actions other than monitoring. Razorback sucker exist and recruit despite a heavy nonnative fish presence in the lake. There are no foreseeable plans to manage nonnative species by removal efforts. Therefore, the razorback sucker population in Lake Mead is likely to remain in a condition similar to current condition under Scenario 1.

Lake Mohave – The razorback sucker population in Lake Mohave has remained steady between 3,000-4,000 individuals over the last several years. The population in Lake Mohave serves as a genetic refuge for the species as they are the most diverse in the system. Razorback sucker recruitment is not occurring in the wild in Lake Mohave because of a dominance of large-bodied nonnative predators; populations are sustained by larvae collected during spawning season, reared in hatcheries and then re-released into the system as adults. The development of a naturally recruited and sustained population is improbable. This population is dependent on management actions mandated by the LCR MSCP and likely to remain so in the future; however, concern was expressed that an inability to implement adaptive management actions or add additional resources to habitat management would cause the population to be unable to cope with future changes. There are no foreseeable plans to manage nonnative species by removal efforts. This resulted in slightly lowered expectations for the Lake Mohave razorback sucker population into the future with demographic conditions remaining in a low category.

Colorado River between Davis and Parker dams (Lake Havasu) - Razorback sucker can now be found from the inflow area of Lake Havasu up-river to the base of Davis Dam, representing one of the more positive reintroduction efforts within the LCRB. The Lake Havasu population of razorback sucker now numbers between 3,000 and 5,000 individuals and was created by stocking efforts after naturally-occurring razorback sucker were extirpated from the area. Much like Lake Mohave, Lake Havasu is dominated by large-bodied nonnative predators and razorback sucker populations are sustained through stocking. The development of a naturally recruited and sustained razorback sucker population is improbable. This population is dependent on management actions mandated by the LCR MSCP and likely to remain so in the future; however, concern was expressed that an inability to implement adaptive management behaviors or add additional resources to habitat management would cause the population to be unable to cope with future environmental changes. There are no foreseeable plans to manage nonnative species by removal efforts. This resulted in slightly lowered expectations for Lake Havasu razorback sucker population into the future with conditions predicted to remain low over 30 years.

Colorado River downstream of Parker Dam – The razorback sucker population in the reach downstream of Parker Dam is also heavily managed by LCR MSCP, but has not seen the same success as upstream populations. Despite continued stocking efforts, razorback sucker populations have not established in the mainstem Colorado, but do persist in a few off channel locations. The habitat in this section is complex and adequate for establishment of a razorback sucker population, but predation from both large-bodied nonnative fishes and avian predators remains high. There are no foreseeable plans to manage nonnative species by removal efforts. The LCR MSCP is trying to reestablish resident populations of razorback sucker in this area;

should adaptive management measures be eliminated, the population level is likely to fall below its already extirpated condition within 30 years.

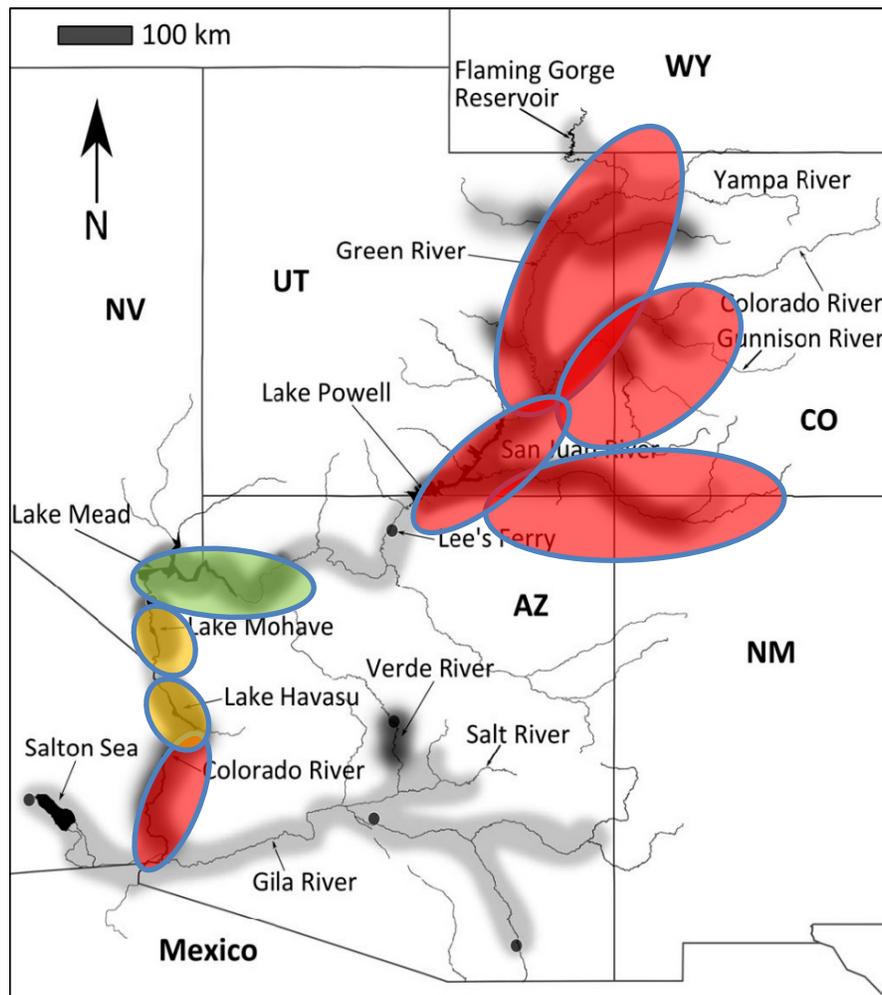


Figure 32. Historical (light gray) and current (dark gray) distribution of the razorback sucker in the Colorado River with different populations indicated by ellipses with colors representing predicted response in demographic species needs under Scenario 1. High condition is indicated by green (average score of 2.26-3), medium condition is indicated by yellow (1.51-2.25), low condition is indicated by orange (0.76-1.5), and extirpated condition is indicated by red (0-0.75).

6.2.2 Scenario 2

Scenario 2 represents continued conservation actions for razorback sucker above and beyond those mandated by law and consistent with current efforts, but assumes stocking success declines as a management tool (Figure 33). The continued conservation actions include all program actions currently occurring in both the upper and lower basin, including nonnative fish management, screen and passage maintenance, augmentation, habitat development and flow management. The novel threat was interpreted in two ways, either that the threat was limited to a hatchery system, thereby making augmentation unsuccessful but not impacting populations already in the system (e.g. hatchery-based disease), or a threat was to fish currently in the system

in addition to those stocked (e.g. novel predator). Both interpretations assume a reduction in the survival of stocked razorback sucker, not a complete arrest of stocking success.

Green River Subbasin – In this scenario, habitat conditions are likely to decline, but not severely, primarily because of the introduction of a novel predator or competitor in the system which would make rearing habitat less available or conducive to survival. Razorback sucker demographic conditions under this scenario would likely decline, but more slowly than under Scenario 1. The razorback sucker population is currently large, which may indicate a long slow decline is likely in the absence of effective stocking. Active management of floodplain wetlands may support the wild recruitment of at least some juveniles even if hatchery stock were not available. Continued management of flow, nonnative populations, canal screens and fish passages would slow the decline of razorback sucker currently stocked in the system. Under this scenario, the Green River subbasin population would likely decline to a low condition in 30 years, but may not be extirpated.

Colorado River Subbasin – In this scenario, habitat conditions for razorback sucker are likely to decline, but not severely, primarily because of the introduction of a novel predator or competitor in the system, which would make habitat less available or conducive to survival. Razorback sucker demographic conditions under this scenario would likely decline, but more slowly than under Scenario 1. Continued management of flow, nonnative populations, canal screens and fish passages would slow the elimination of razorback sucker currently stocked in the system. Under this scenario, the Colorado River subbasin population would likely decline to a low condition in 30 years and may be approaching extirpation.

San Juan River Subbasin – The San Juan River razorback sucker population is currently the smallest of the upper basin riverine populations and is reliant on stocking. Under Scenario 2, the San Juan River subbasin population would see a more dramatic decline in demographic condition than in the Green or Colorado subbasins. The population in the San Juan River shows signs of bottlenecks at multiple stages of development, including the larval stage. Although off-channel and backwater habitat is actively being developed, the system has a paucity of nursery habitats available to the razorback sucker. Fish passage is currently blocked by the waterfall; the blockage is expected to persist as lake levels drop. The predatory nonnative fishes are limited to channel catfish, which can compete with razorback sucker for niche space and become piscivorous at large sizes. Although declines in the razorback sucker population in this basin are predicted to be substantial in this scenario, they are predicted to be less dramatic than in Scenario 1, indicating that management actions in addition to stocking are important.

Lake Powell – The Lake Powell razorback sucker population is also expected to decline under Scenario 2, but at rates slower than the other upper basin populations. Other than population monitoring, management actions are currently not occurring in Lake Powell. An anticipated decline in Razorback Sucker population is based on a lack of hatchery fish migrating from other upper basin populations into the Lake Powell system. Without augmentation, the razorback sucker population levels are likely to decline.

Lake Mead – As noted above, very few management actions are occurring in Lake Mead to support the only successfully recruiting razorback sucker population in either basin. The

Razorback Sucker population in Lake Mead has not been augmented by hatchery stock, although a few research fish have been released to help determine the location of other fish in the population. Razorback sucker persist and recruit at a low level, despite a heavy nonnative fish presence in the lake. There are no foreseeable plans to manage nonnative species by removal efforts. Therefore, the Razorback Sucker population in Lake Mead is likely to remain in a condition similar to current condition under Scenario 2.

Lake Mohave – The razorback sucker population in Lake Mohave is heavily dependent on the management action of capturing larvae during spawning season, growing the fish in off-channel or hatchery ponds and returning them to Lake Mohave as adults large enough to survive in a lake dominated by nonnative predators. If this management tool were to decrease in effectiveness, it would have a substantial effect on the razorback sucker populations from a demographic standpoint. Many participants predicted declines in both the adult population and the resulting spawn and larval presence, indicating that a negative feedback loop would make maintaining this genetically robust population very difficult. It is important to note that in a system dominated by nonnative predators, it is unlikely that a novel predator could increase predation significantly above current levels; therefore, the threat was more likely considered a disease or other factor causing declines in survival after stocking. There are no foreseeable plans to manage nonnative species by removal efforts.

Colorado River between Davis and Parker dams (Lake Havasu) – The razorback sucker population downstream of Davis Dam is likely to follow a similar pattern to that of Lake Mohave. Should stocking success decline, the Razorback Sucker population would likely decline as well. There are no foreseeable plans to manage nonnative species by removal efforts in this area.

Colorado River below Parker Dam – The area downstream of Parker Dam is currently stocked with razorback sucker, yet survival remains low. The habitat present below Parker Dam is thought sufficient, but predation is high from both birds and nonnative fish. There are no foreseeable plans to manage nonnative species by removal efforts. A decline in the effectiveness of razorback sucker stocking would likely extirpate this population in the 30 years considered as future, if not before.

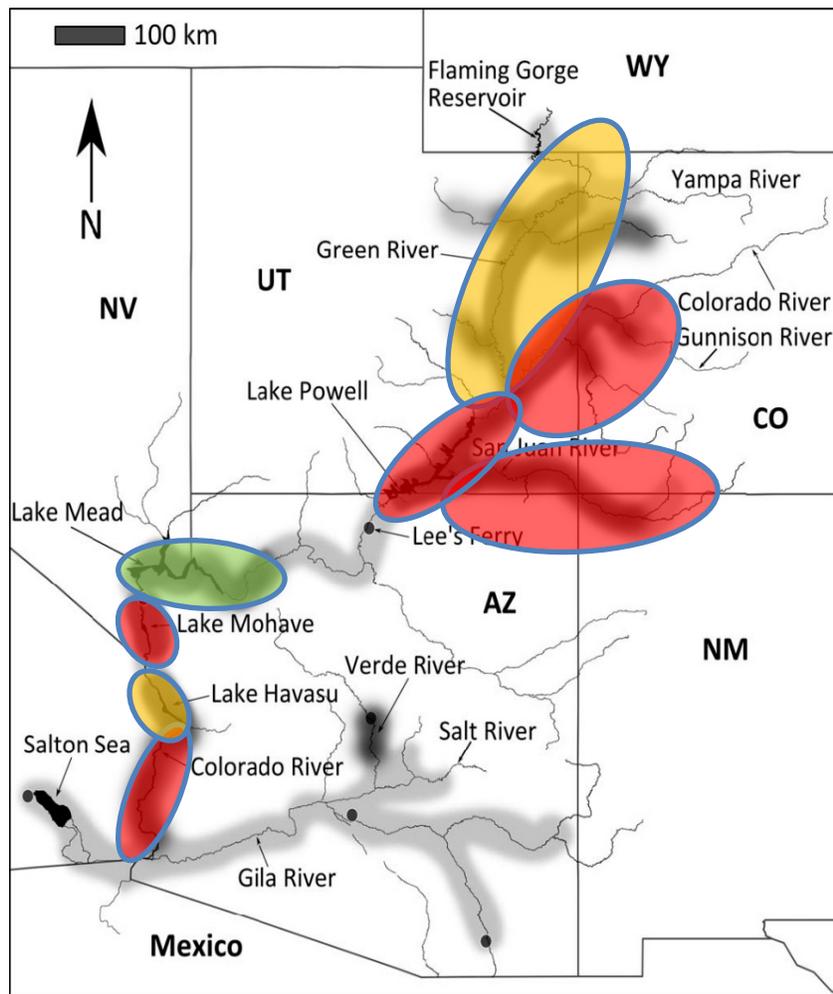


Figure 33. Historical (light gray) and current (dark gray) distribution of the razorback sucker in the Colorado River with different populations indicated by ellipses with colors representing predicted response in demographic species needs under Scenario 2. High condition is indicated by green (average score of 2.26-3), medium condition is indicated by yellow (1.51-2.25), low condition is indicated by orange (0.76-1.5), and extirpated condition is indicated by red (0-0.75).

6.2.3 Scenario 3

Scenario 3 represents a continuation of all management actions currently occurring under the UCREFRP, SJRIP, GCDAMP and LCR MSCP. These actions include flow and habitat management, nonnative fish removal, maintenance of screens and passages, research and monitoring to varying degrees across the populations. In all razorback sucker populations, slight increases in condition are anticipated with continuation of current management actions (continuing a trend developed over the last thirty years of management actions). Over the past 30 years, the programs have effectively developed stocking programs, managed flows to mimic natural flows to the extent possible and respond to biological triggers, removed barriers to migration, added canal screens to prevent entrainment, and created or improved habitat specifically managed for razorback sucker. The Programs have repeatedly identified and

eliminated threats through their adaptive nature and that trend is expected to continue. When compared to the improvements over the last thirty years, the improvement rate is expected to decline, as some of the largest threats (e.g. nonnative predators) are persistent and difficult to eliminate. The improvements are anticipated to be larger in the upper basin in comparison to the lower basin (Figure 34). Changes in the Green and Colorado river subbasins are driven by demographic improvements as much of the physical habitat improvements thought to be necessary for population success have been accomplished. A number of habitat improvements or barrier elimination projects in the San Juan are still underway.

The Lake Mead razorback sucker population is expected to improve less because of the lack of current management actions associated with that population. Should the adaptive programs in the lower basin choose to add management actions, the gains would likely increase. There are no foreseeable plans to manage nonnative species by removal efforts in any lower basin population so the increases in condition are expected to be driven primarily by increasing off-channel and backwater habitat to the extent feasible.

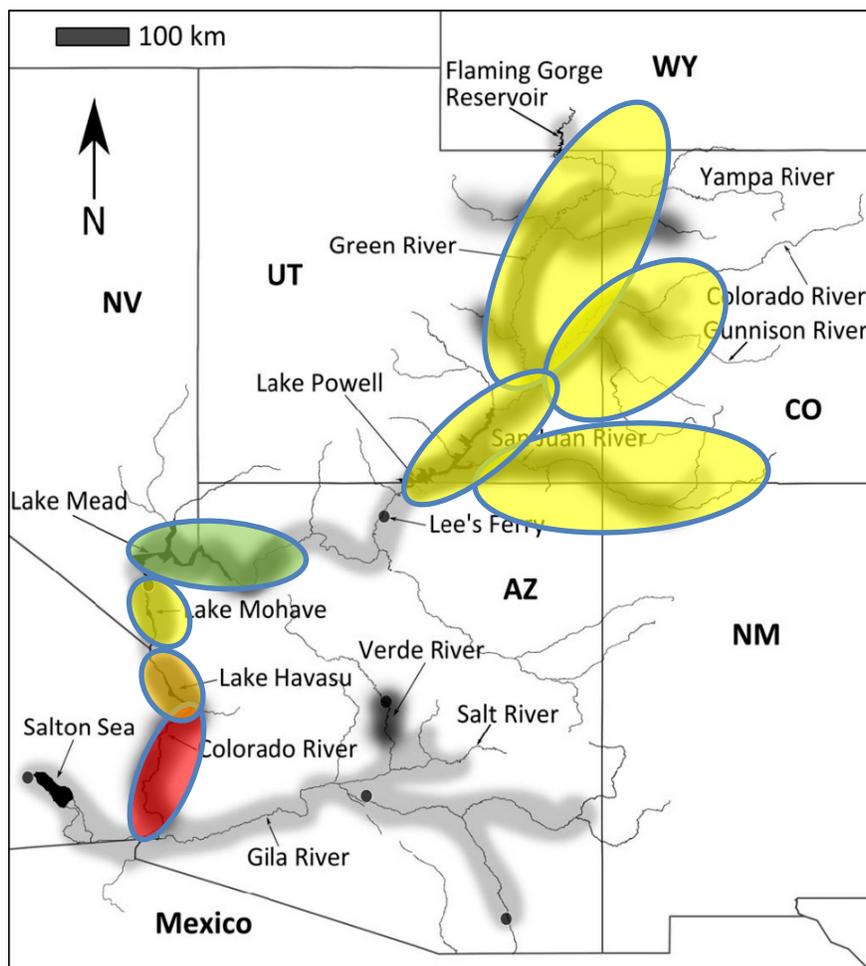


Figure 34. Historical (light gray) and current (dark gray) distribution of the razorback sucker in the Colorado River with different populations indicated by ellipses with colors representing predicted response in demographic species needs under Scenario 3. High condition is indicated by green (average score of 2.26-3), medium condition is indicated by yellow (1.51-2.25), low condition is indicated by orange (0.76-1.5), and extirpated condition is indicated by red (0-0.75).

6.2.4 Scenario 4

Scenario 4 represents the continuation of all razorback sucker management actions occurring in Scenario 3, but anticipates an increase in effectiveness of those actions, specifically that support recruitment (Figure 35). The actions include flow and habitat management, nonnative fish removal, research and monitoring to varying degrees across the populations. Scenario 4 anticipates dramatic improvement in some aspect of management. For example, this could include increasing fish passage structures to increase connections (e.g. over the San Juan Waterfall), increases in the number or distribution of floodplain wetland habitats (in the UCRB) or off-channel backwater habitat (in the LCRB) allowing substantial razorback sucker recruitment to occur to the juvenile life stage, or dramatic decreases in the resident populations of nonnative fishes due to increased effectiveness of nonnative removal. Increased effectiveness of nonnative removal in the upper basin could occur from spike flows, which could decrease smallmouth bass populations on a river-wide scale by decreasing parental protection of larvae. Spike flows are an experimental technique where flows and/or turbidity are increased just after bass larvae hatch, which moves adults off the nest and subjects the larvae to predation (Bestgen *et al.* 2018). Preliminary results from a conveniently timed rainstorm in 2015 show an opportunity for river-wide reductions in year-class development of smallmouth bass. As in Scenario 3, the effects of these changes are likely larger in upper basin populations and lowest in Lake Mead where management actions are limited. There are no foreseeable plans to manage nonnative species by removal efforts in the lower basin. Projected increases in the lower basin assume development of sufficient backwater or off-channel habitat to allow recruitment to occur.

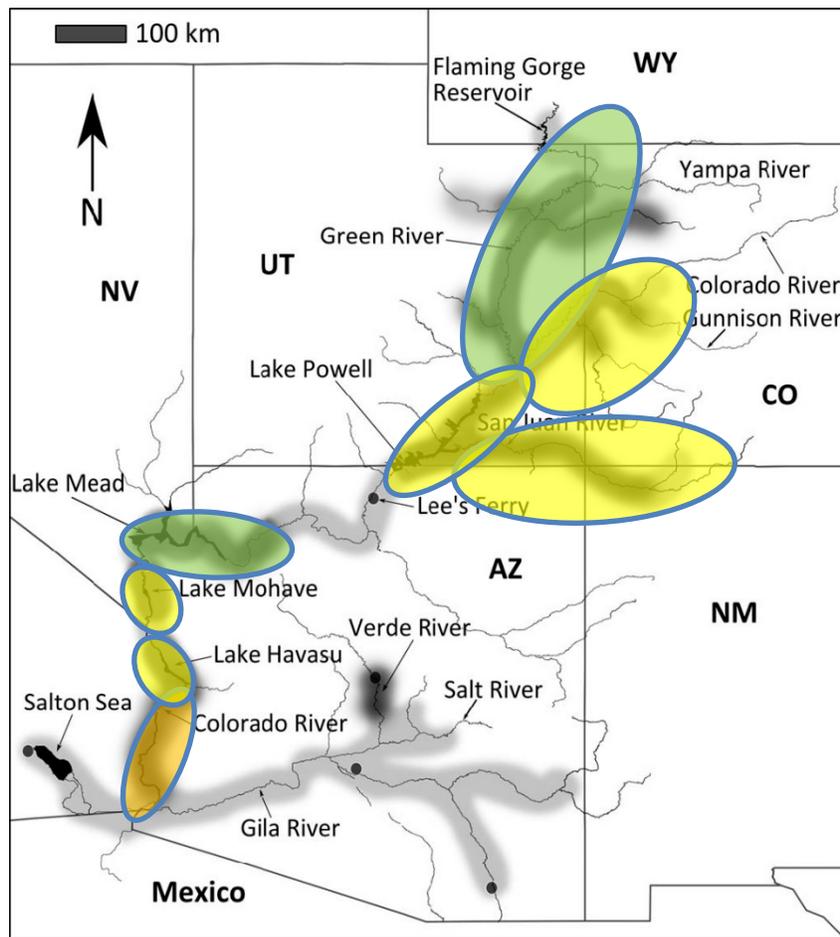


Figure 35. Historical (light gray) and current (dark gray) distribution of the razorback sucker in the Colorado River with different populations indicated by ellipses with colors representing predicted response in demographic species needs under Scenario 4. High condition is indicated by green (average score of 2.26-3), medium condition is indicated by yellow (1.51-2.25), low condition is indicated by orange (0.76-1.5), and extirpated condition is indicated by red (0-0.75).

6.2.5 Scenario 5

Scenario 5 represents a dramatic shift in our ability to manage the ecosystem, primarily in the realm of nonnative fish control or habitat. As in Scenarios 3 and 4, all management actions and commitments for Razorback Sucker continue, but in this case, the increase in effectiveness is dramatic (Figure 36). Participants believed the development of this scenario was unlikely, but wanted to acknowledge that many strides have been made in humankind’s ability to manage invasive plant species and that such an increase may also occur in aquatic systems during the next 30 years, potentially through genetic means.

If nonnative fishes were able to be removed from the system on a large scale or if habitat modifications could be more effective at providing shelter for key life stages, the effects on razorback sucker would likely be dramatic. The cumulative effects of nonnative fishes ranging from small nonnative cyprinids to large predators is likely limiting the return of populations to

their previous sizes. Should tool(s) be available to clear the system of invasive effects or provide suitable habitat in a novel way, the result would likely be dramatic increases in razorback sucker demographic criteria. Upper basin populations would likely return to high condition, while lower basin populations may return to a moderate condition. The effects in lower basin populations are thought to be smaller because of the continued desire for nonnative sportfish in the major reservoirs of the Southwest. If elimination of nonnative fishes were possible, it may be politically untenable for some species.

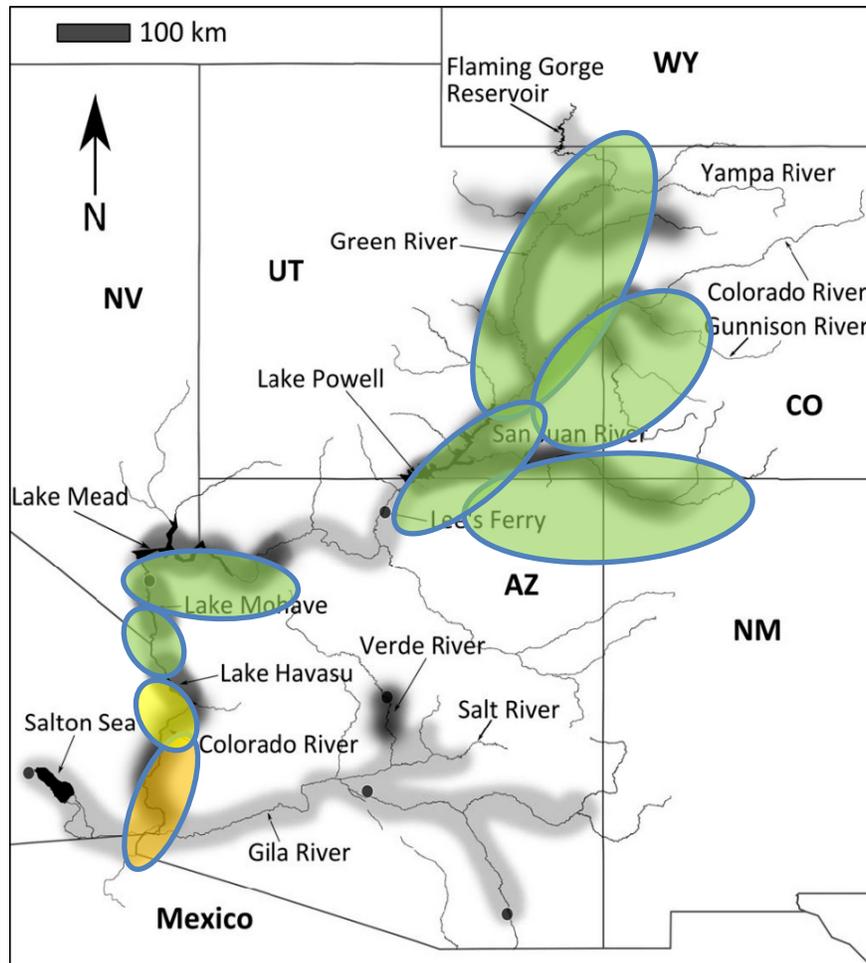


Figure 36. Historical (light gray) and current (dark gray) distribution of the razorback sucker in the Colorado River with different populations indicated by ellipses with colors representing predicted response in demographic species needs under Scenario 5. High condition is indicated by green (average score of 2.26-3), medium condition is indicated by yellow (1.51-2.25), low condition is indicated by orange (0.76-1.5), and extirpated condition is indicated by red (0-0.75).

6.2.6 Future Viability

6.2.6.1 Upper Basin

The results of the management based future scenarios predict a range of future conditions ranging from restoration of most populations to a high condition to returning to the low condition seen in the last century (Figure 37). Multiple management actions have been taken to date to improve razorback sucker populations from previous low levels. After populations in the upper basin crashed in the early 1990’s, individual razorback sucker were brought into hatcheries to form a broodstock. After decades of stocking, some populations of stocked fish are growing as annual survival of stocked fish increases. Flow recommendations have been developed and implemented at multiple reservoir systems in the upper basin in an attempt to mimic the natural hydrograph to the extent possible. In the Green River, flow recommendations include biologically based triggers that increase flows after razorback sucker larvae are detected in the river, creating a connection to floodplain wetlands, allowing larval fish to enter managed wetland systems. Fish screens and fish passages have been constructed to prevent entrainment in canals and allow for migration of native species across the basin.

With these management actions, razorback sucker populations have shown dramatic improvements in redundancy. Razorback sucker can now be found across all upper Colorado River subbasins, in both mainstems and tributaries. Genetic integrity has been managed through the stocking process and genetic diversity has remained consistent with the diversity found when the populations were first studied. Resiliency of the populations remains low because of the lack of recruitment in the populations. Scenarios 3, 4 and 5 include predicted improvements in resiliency of the populations based on continued management actions. Scenarios 1 and 2 represent declines in redundancy and resiliency of the upper basin population as management actions would reduce in scope or effectiveness.

Predictions of Future Conditions in Upper Basin Populations

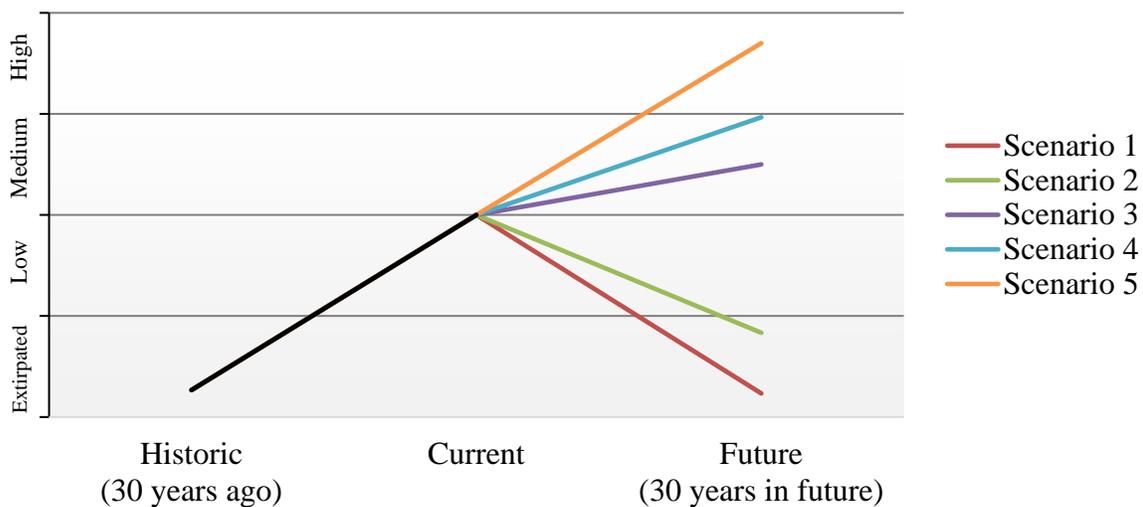


Figure 37. Prediction of razorback sucker population responses under the five future scenarios for all upper basin populations.

6.2.6.2 Lower Basin

The results of the management based future scenarios predict a much narrower range of future conditions for Razorback Sucker populations in the lower basin than in the upper basin mostly because of the dominance of nonnative predators in the lower basin that are managed and valued as sportfish (Figure 37). Razorback sucker populations are currently managed across the basin, and efforts attempts develop new populations across historic habitat via stocking continue. The resident populations of striped bass and flathead catfish in the large reservoirs within the lower Colorado River basin are likely to continue to suppress or eliminate razorback sucker recruitment. While some off-channel habitats may continue to be developed and lead to improved populations, it is unlikely that populations in the lower basin will ever be considered high condition. With the possible exception of Lake Mead, lower basin populations are not resilient in the face of nonnative predation and are unlikely to become so. Genetic integrity is intact and more robust than in the upper basin populations, but only through a heavily managed re-introduction program. Redundant populations of Razorback Suckers are currently in place but not successful in all populations, but would be at risk without continued management.

Predictions of Future Conditons in Lower Basin Populations

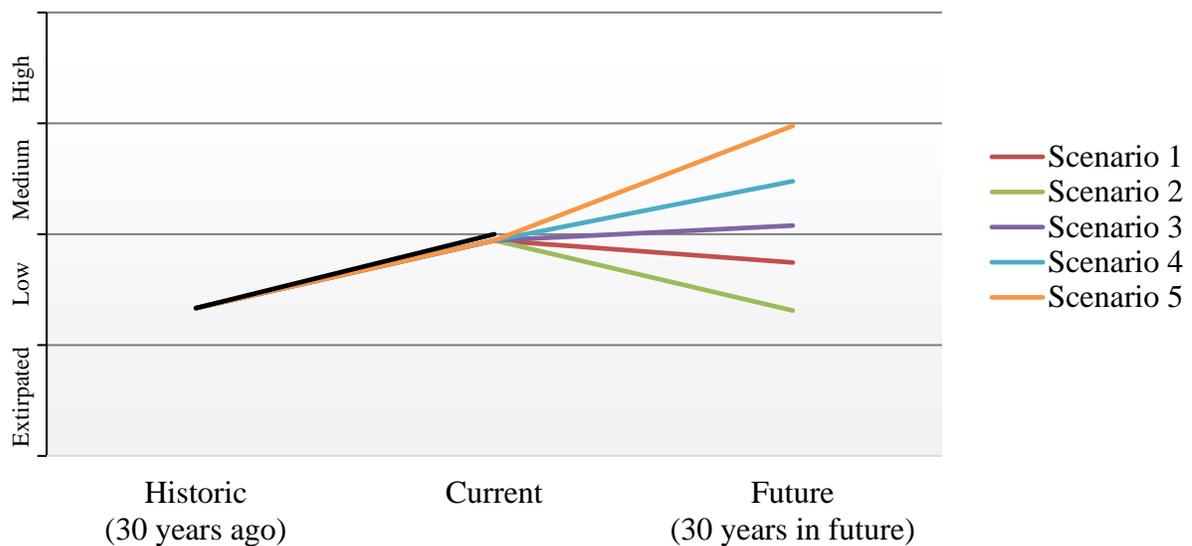


Figure 38. Prediction of razorback sucker population responses under the five future scenarios for all Colorado River lower basin populations.

6.2.6.3 Summary

When razorback sucker populations across both basins are considered together, predicted future condition ranges from high to low, with a larger distribution of values in the upper basin driving the range (Figure 39). The current condition of razorback sucker has been driven by conservation actions that have occurred over the last 30 years, and it is likely that the population condition in the future will also be driven by those management actions. If management actions continue at

current or increasing levels of success, improvements are expected in resiliency. Should management actions cease, resiliency, redundancy and representation of the species are likely to decline.

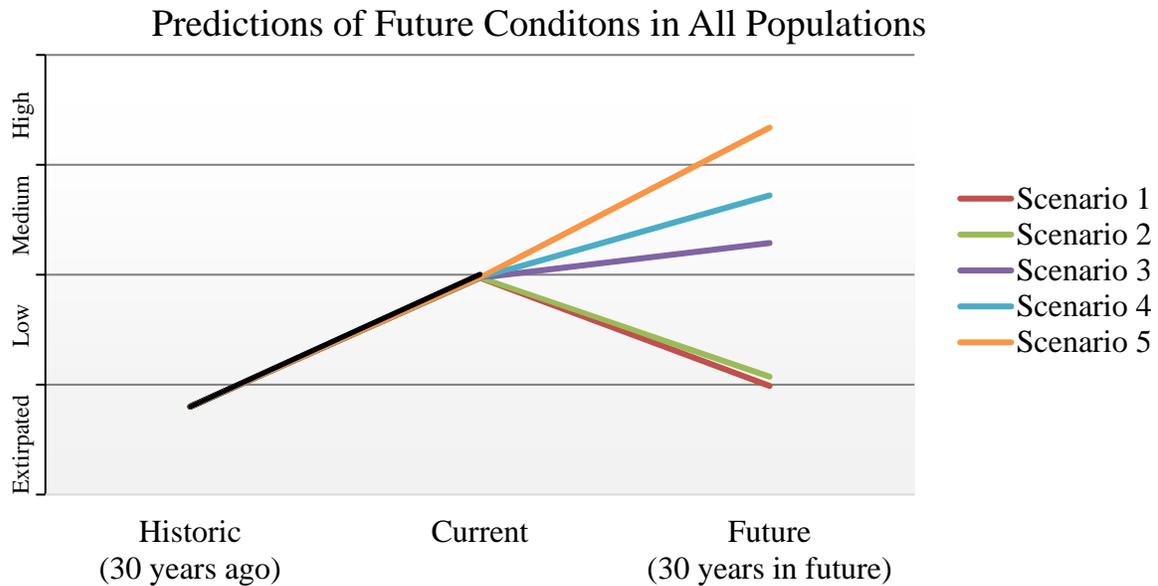


Figure 39. Prediction of razorback sucker population response under the five future scenarios for all Colorado River populations.

Based on this range of potential future condition, we asked the Science Team participants to predict likelihood of each scenario using the values presented in Table 16.

Table 16. Likelihood values used to assess future condition.

Term	Likelihood of the outcome
Virtually certain	99-100% probability
Extremely likely	95-100% probability
Very likely	90-100% probability
Likely	66-100% probability
About as likely as not	33-66% probability
Unlikely	0-33% probability
Very unlikely	0-10% probability
Extremely unlikely	0-5% probability

Both scenarios 4 and 5 were judged unlikely at both the 30-year and 100-year time frame, with the possibility of population scale effects being very unlikely at 30 years (Table 17). Participants judged Scenario 3 to be the most likely scenario over the 30-year time frame, but indicated that over a longer time frame of 100 years, that both Scenario 2 and Scenario 3 were equally likely. Participants also noted that Scenario 1 was unlikely in the near term as some funding arrangements are more certain over that time frame than others (e.g. LCR MSCP and GCDAMP) or under current negotiation with strong partner support (e.g. UCREFRP and SJRIP). Scenario 1 became more likely in the long term based on the expiration date of those agreements.

Table 17. Likelihood of scenarios as predicted by the science group of occurring at 30 years and 100 years.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
30 yrs	Unlikely	About as likely as not	Very likely	Unlikely	Very unlikely
100 yrs	About as likely as not	Likely	Likely	Unlikely	Unlikely

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8 APPENDIX A: DELPHI METHODS

For the current Delphi questionnaire, a multicriteria analysis (MCA) framework was devised to quantitatively distinguish expert opinions regarding the influence of factors on viability and to identify potential geographical differences in influence (e.g., UCRB and LCRB). There are various approaches to constructing a MCA. For the current process, the MCA was developed using a simple example of a weighted sum model (Natural Resources Leadership Institute 2016) and an example of using this type of model in an ecological Delphi process (Grech and Marsh 2008). In this model, a list of influencing factors are first ranked and weighted by each participating expert. Then each expert rates the same list of factors for geographic locations (i.e., the UCRB and LCRB). Ratings for each basin were multiplied by the weights assigned to the factors and then summed to create a composite index by basin. For purposes of the survey, and as described previously for this document, we defined the UCRB as all razorback sucker populations above Glen Canyon Dam and the LCRB as all populations below Glen Canyon Dam.

8.1 Participant Selection

Biologists working with razorback sucker in both the UCRB and LCRB were asked to provide a list of other biologists in their region who have worked with the species, including retired as well as recently hired biologists. Fifty-six of 87 invited biologists participated in the first-round questionnaire, and 47 biologists continued to participate in the second and third rounds. Biologists had a wide range of views, assumptions, perceptions and/or sources of information when completing these surveys.

8.2 First Round Scoring Survey

In the first Delphi round, participants were asked to rank and weight a list of factors and subfactors potentially influencing the near-term viability of razorback sucker (within the next 30 years).

Table 18. Major factors potentially influencing Razorback Sucker population viability as presented to participants in the first Delphi round (subfactors are indicated in parentheses) as they relate to the 2002 recovery goals recovery factor criteria.

Factors Potentially Influencing Viability of razorback sucker during the Next 30 Years, Listed Alphabetically	Recovery Goal Factor	Recovery Factor Criteria from 2002 recovery goals
Climate Change	A	Adequate habitat and range for recovered populations provided.
Conservation and Recovery Efforts (augmentation, non-native fish removal, program funding, research and monitoring)	D	Adequate existing regulatory mechanisms.
Genetic Factors (diversity, hybridization)	E	Other natural or manmade factors for which protection has been provided.
Habitat (flow regime/connectivity, land use, water management/habitat availability, water temperature)	A	Adequate habitat and range for recovered populations provided.

Non-native and Invasive Species (competition, habitat effects, predation)	C	Adequate protection from diseases and predation.
Overutilization (use of species for commercial, recreational, scientific, or educational purposes)	B	Protection from overutilization for commercial, recreation, scientific, or educational purposes.
Parasites and Diseases	C	Adequate protection from diseases and predation.
Pollutants (heavy metals, runoff, spills)	E	Other natural or manmade factors for which protection has been provided.

The first round questionnaire was administered as an internet survey that was pretested internally with a small group of fisheries biologists and USFWS project leads. Following the pretest, the categories of factors and definitions of factors were revised based on input received. Initially, water management factors were separate from habitat, but it was found that these were being weighted equally by the pretest group. Because it appeared that these factors would not be distinguishable, they were combined.

The ranking and weighting exercise involved three steps. For the first step, each participant ranked eight major categories of factors in perceived order of importance and assigned each factor a weight out of 100 total points. For the second step, participants weighted subfactors for five of the eight major categories. Each subfactor could be weighted up to or equal to the assigned major factor for that category. For example, if a participant assigned a weight of 10 to genetic factors (major category), then the participant could give both genetic diversity and hybridization (subfactors) any weight between 0 and 10. For the third step, participants rated each of the razorback sucker viability factors for the UCRB and LCRB using a 1–5 rating scale with 1 representing “not at all influential” and 5 indicating “very influential.”

The invitation to participate in the first round survey (Appendix A) included definitions of factors, subfactors, and viability, and information regarding internet survey access. Participants were also asked if they wanted to share general thoughts and observations about razorback sucker abundance, distribution, and diversity, which are essential characteristics that contribute to a species’ ability to sustain populations in the wild over time (D. R. Smith *et al.* 2018) .

8.3 Second Round Comment Survey

In the second round, each participant was sent a customized report indicating how their weightings compared with the group response. The report flagged any individual’s factor and subfactor weightings that were higher or lower than the group average by one standard deviation. Each participant was asked to comment on their higher and lower weightings, as well as to provide any other observations that they wanted to share. Participants were not asked to reweight factors in this round because they had not yet had the opportunity to review comments from other participants.

8.4 Third Round Scoring Survey

The third round survey was also a customized report showing how each participant’s factor and subfactor weights compared with the group’s; this time the weights were presented with the

second round comments from all participants. In this round, participants were asked to consider the comments and reweight each factor and subfactor (they could keep the existing weight or select a higher or lower weight based on their reaction to comments). Definitions of the factors and subfactors provided in the first round were repeated to help participants focus weighting on a common understanding of the factors and subfactors.

Because there is no standard type of data collection for a Delphi process (in this case, an MCA model was developed), there is also no standardized method of assessing change between rounds. In general, Delphi assessment is concerned with the degree to which participants agreed more with one another in subsequent rounds after consideration of comments. Measures of central tendency (mean, median, mode) and dispersion (variance, standard deviation, standard error, range, interquartile range) can all be appropriate for this purpose (Holey *et al.* 2007; Hsu and Sandford 2007). The MCA model (factor weighting and ranking) lends itself to use of the mean, standard deviation, and standard error, as well as to statistical tests such as ANOVA; all of these statistics were utilized in evaluating the results of the razorback sucker SSA Delphi process.

8.5 Delphi Results

This section presents participant characteristics (years of experience and knowledge of the basins in which participants primarily worked), weighting modifications from Round 1 to Round 3, and outcomes of the weighting process in terms of the perceived influence of factors and subfactors on the viability of razorback sucker.

8.5.1 Participant Characteristics

Among the 47 participating biologists, experience working with razorback sucker ranged from 1 to 45 years, averaging 17 years and representing 815 collective years of experience (Figure 40). Of the 47 participants, 22 are biologists who primarily worked in the UCRB, 17 primarily worked in the LCRB, and 8 have experience working in both basins.



Figure 40. Participant years of experience working with razorback sucker recovery and monitoring.

8.5.2 Factor Scoring Changes from Round 1 to Round 3

On average, participants weighted nonnative predation as the most influential factor, followed closely by two habitat-influencing factors: flow regime and water management (Table 19 and Figure 41). Table 19 presents descriptive statistical comparisons for the distribution of individual responses from Rounds 1 and 3 (mean, median, standard deviation, minimum value, and maximum value), as well as the change in standard deviation and range between rounds. Statistics indicating variability in weightings (the interquartile range and the minimum and maximum weights) suggest that there were higher levels of agreement regarding the less influential factors. In particular, the interquartile range was less than 10 for genetic factors (genetic diversity and hybridization), pollutant factors (heavy metals, runoff pollution, contaminant spills), parasites and diseases, and overutilization, indicating that at least half of the participants weighted these factors within 10 points of one another.

Figure 41 presents a comparison of the means. The error bars in Figure 41 represent ± 2 standard errors from the mean (approximately the 95% confidence interval of the mean). Comparison of the error bars for each factor illustrate that there were no significant changes in mean weighting from Round 1 to Round 3, which was also confirmed by ANOVA tests (ANOVA, $p < 0.05$ for all factors). There were no changes in the rank order of mean weights between scoring rounds. The most noticeable change was an increase in weights assigned to the five top-ranked factors, with nonnative predation receiving the largest increase in weight. However, variability in weights assigned to the most influential factors remained high in Round 3, as compared with the lower-weighted factors.

Table 19. Descriptive statistics comparing Round 1 weighting with Round 3 weighting.

Factor	Round 1						Round 3					
	Mean	Standard Deviation	Median	IQR ^a	Minimum	Maximum	Mean	Standard Deviation	Median	IQR ^a	Minimum	Maximum
Nonnative Predation	23.0	11.7	20	20	4	60	27.6	12.9	25	15	10	60
Habitat - Flow Regime	20.6	13.8	20	20	3	60	22.8	13.1	20	18	4	50
Habitat - Water Management	20.1	12.5	20	14	3	50	22.0	12.1	20	10	4	50
Recovery - Funding	15.2	12.7	10	10	0	60	17.7	12.6	15	8	2	60
Recovery - Augmentation	15.0	12.0	10	15	0	60	16.9	11.3	15	15	0	50
Recovery - Nonnative Removal	13.8	11.9	10	10	0	60	13.5	12.0	10	10	0	60
Recovery - Research/ Monitoring	12.8	11.0	10	14	0	60	12.5	8.3	10	10	1	50
Nonnative Competition	11.8	11.1	10	15	0	50	12.2	9.5	10	10	0	40
Nonnative/Invasive Habitat Effects	9.9	10.5	8	15	0	50	9.9	7.9	10	15	0	35
Habitat - Water Temperature	9.9	12.0	5	15	0	50	9.5	9.1	7	15	0	50
Climate Change	8.7	6.5	6	15	0	25	9.1	6.4	8	14	0	25
Habitat - Land Use	8.0	10.8	4	11	0	50	8.3	9.5	5	10	0	50
Genetic Diversity	5.9	5.2	4	8	0	20	5.9	4.9	5	8	0	20
Heavy Metals	3.8	3.1	3	4	0	10	3.7	2.7	3	4	0	10
Hybridization	3.3	3.1	2	3	0	12	2.9	2.8	2	3	0	10
Parasites and Diseases	3.1	2.4	3	1	0	10	2.6	1.9	2	1	0	8
Runoff Pollution	2.3	2.4	2	3	0	10	2.1	2.0	2	2	0	10
Contaminant Spills	2.1	2.6	1	4	0	10	2.2	2.3	2	3	0	10
Overutilization	1.6	2.0	1	3	0	5	1.4	1.9	1	2	0	5

^aThe interquartile range is the range of the middle 50 percent of responses, or the difference between the 75th percentile and the 25th percentile.

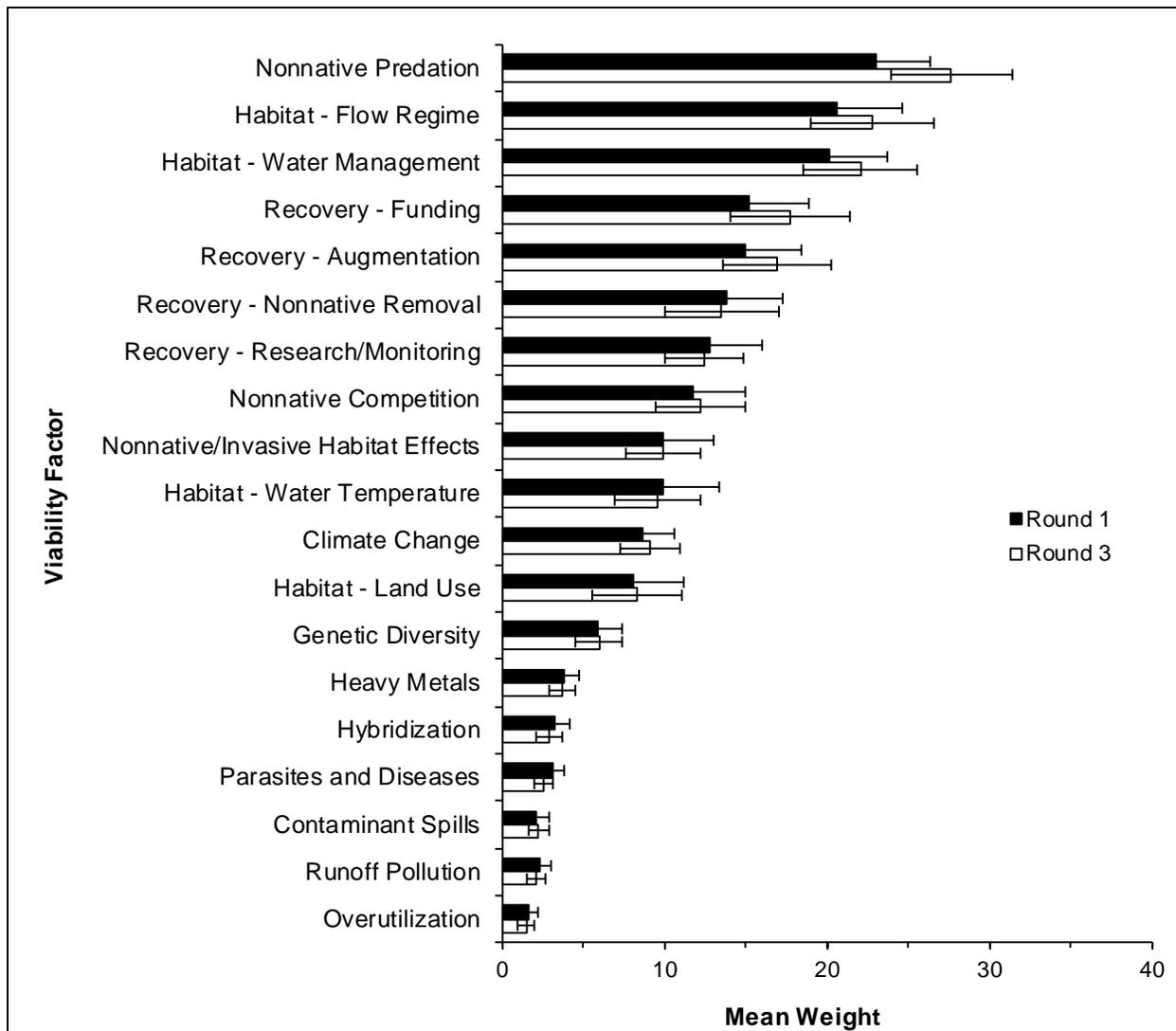


Figure 41. Mean weights assigned to factors potentially influencing viability of razorback sucker during the next 30 years (± 2 Standard Errors).

Overall, there was a reduction in variability of factor weights after Round 3 with the notable exception of nonnative predation which increased in variability, and the variance for nonnative removal also increased slightly (Figure 42). It is notable that all participants who changed the weight that they had assigned to nonnative predation in Round 3 increased their scores from Round 1; this was the only factor for which none of the participants decided to decrease their weight from Round 1. The increase in variability for nonnative predation was due to differences in the degree to which various participants chose to increase the weight. Thus, there was an overall increase in the group’s perceived weight of influence for nonnative predation and, hence, increased agreement that this factor is an important influence on viability. However, because the range in weights remained high, there continued to be disagreement regarding the degree to which nonnative predation influences viability.

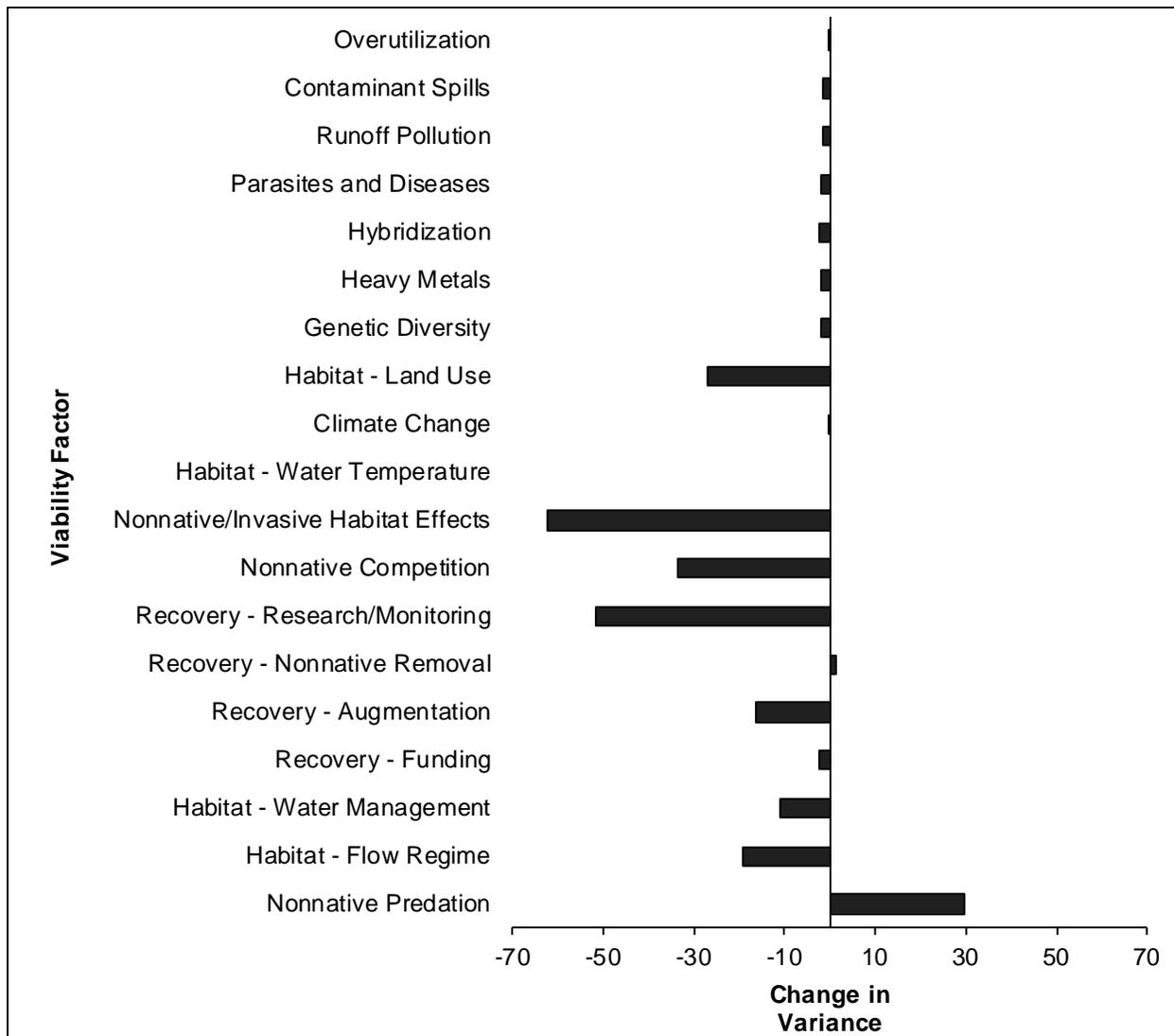


Figure 42. Change in variance for factor weights from Round 1 to Round 3.

The pattern was different for nonnative removal efforts, which also saw slightly increased variability from Round 1 to Round 3 (Figure 21). For this factor, there was notably more change in weights in Round 3. Twelve participants decreased the weight they assigned to this factor while nine increased the weight. The two groups changed their weightings in roughly equal proportions.

The greatest reduction in the variability of scores between Round 1 and Round 3 was for nonnative and invasive habitat effects. Comments regarding this factor indicated that in Round 1 some participants were thinking only about nonnative fish species while others were also thinking about other invasive aquatic species and invasive riparian vegetation such as Tamarisk (the definition provided in the survey intended for this factor to include all of these). Thus, the shared understanding of this factor and other factors likely improved in Round 3, which is one of the purposes of using a Delphi process.

There was little change in variability for the seven lowest ranked factors (genetic diversity, heavy metals, hybridization, parasites and diseases, runoff pollution, contaminant spills, and overutilization), indicating that there was already a high level of agreement in Round 1 that these are less-influential factors on razorback sucker viability.

8.5.3 Factor Weighting Outcomes – Analysis of Variance

A significant difference was found in an analysis of the group's Round 3 mean weights for razorback sucker viability factors (ANOVA, $F_{18,892}=39.0$, $p<0.001$). Based on a consideration of post hoc comparisons (Table 20), the factors can be meaningfully grouped into four tiers of influence on Razorback Sucker viability in the following manner:

- In the top tier of influence are the three factors that the group weighted highest: nonnative predation, and the top two habitat-influencing factors of flow regime and water management. Mean weights for these three factors all exceeded 20 in the Round 3 results.
- The second tier primarily includes conservation and recovery efforts: program funding, augmentation, nonnative removal, and research and monitoring. The group's mean weights for these factors ranged from a high of 17 to a low of 12. Nonnative competition was also included with this tier at the lower end of the range with a mean weight of 12.17.
- The third tier consists of secondary factors that are related to the top tier of factors; these are habitat-quality influencing factors with mean weights between 10 and 3. These factors include habitat effects of nonnatives, water temperature, climate change, land use, and heavy metals. Genetic diversity is also grouped into this tier.
- In the fourth tier are the factors that the group assessed as being the noninfluential factors, at least at the species scale: hybridization, parasites and diseases, contaminant spills, runoff pollution, and overutilization. These factors all had mean weights less than 3. Some participants thought that some of these factors were being underrated by the group or that these factors may have effects for some localized populations, such as hybridization, runoff pollution, and risk of contaminant spills.

8.5.4 Basin Differences in Viability – Multicriteria Analysis Results

As previously stated, participants were also asked to rate factors and subfactors by basins on a 1–5 scale. In the MCA model, ratings by basin were multiplied by the weights assigned to the factors and subfactors to create a composite index by basin. This was done individually by each participant and then averaged for the group. Intuitively, the factor with the highest weight is the most critical one; however, in terms of which factors most distinguish differences between basins, this may not be the case. Instead, it is necessary to examine how sensitive the composite index for each basin was to the composite weights of each factor. This is referred to as sensitivity analysis. There are various ways to conduct a sensitivity analysis depending on the assessment method used (Triantaphyllou and Sanchez 1997). In this case, an appropriate indicator is the mean relative weight of each factor (Figure 43). Objectively, this number is the proportionate change in the difference between the composite indices for each basin that would occur if the given factor were excluded from the model. If participants made no distinction between the

Table 20. Post-hoc, all-pairwise comparison analysis based on Tukey’s honest significant differences test, Round 3 group weights.

Factor	Mean Weight	Homogeneous Groups^{a*}	Shared Group^a
Nonnative Predation	27.64	A	A
Habitat - Flow Regime	22.77	AB	A
Habitat - Water Management	22.04	AB	A
Recovery - Funding	17.68	BC	C
Recovery - Augmentation	16.92	BC	C
Recovery - Nonnative Removal	13.52	CD	C
Recovery - Research/Monitoring	12.47	CD	C
Nonnative Competition	12.17	CD	C
Nonnative/Invasive Habitat Effects	9.85	DE	E
Habitat - Water Temperature	9.53	DE	E
Climate Change	9.09	DEF	E
Habitat - Land Use	8.28	DEFG	E
Genetic Diversity	5.94	EFGH	E
Heavy Metals	3.67	EFGH	E
Hybridization	2.94	FGH	H
Parasites and Diseases	2.55	GH	H
Contaminant Spills	2.22	GH	H
Runoff Pollution	2.07	GH	H
Overutilization	1.45	H	H

^aLetters denote groupings of factors in the post-hoc test, so the first three factors share categorization in “Group A,” the next five factors all share categorization in “Group C,” and so on.

UCRB and LCRB for a given factor, then that factor would have a mean relative weight of zero. Looking at the example of nonnative predation, this factor has a mean relative weight of 0.258. Expressed as a percentage, this value indicates that the group’s overall rating differences between the UCRB and LCRB would be 25.8% less if nonnative predation were excluded from the model. Because this value is in the UCRB column, this indicates that the group, on average, rated this factor higher for the UCRB. However, the error bar overlaps zero, reflecting the previously discussed variability in ratings that participants assigned to nonnative predation, as well as variability in how participants rated the influence of this factor for razorback sucker populations in the respective basins, with many rating nonnative predation equally important in both basins.

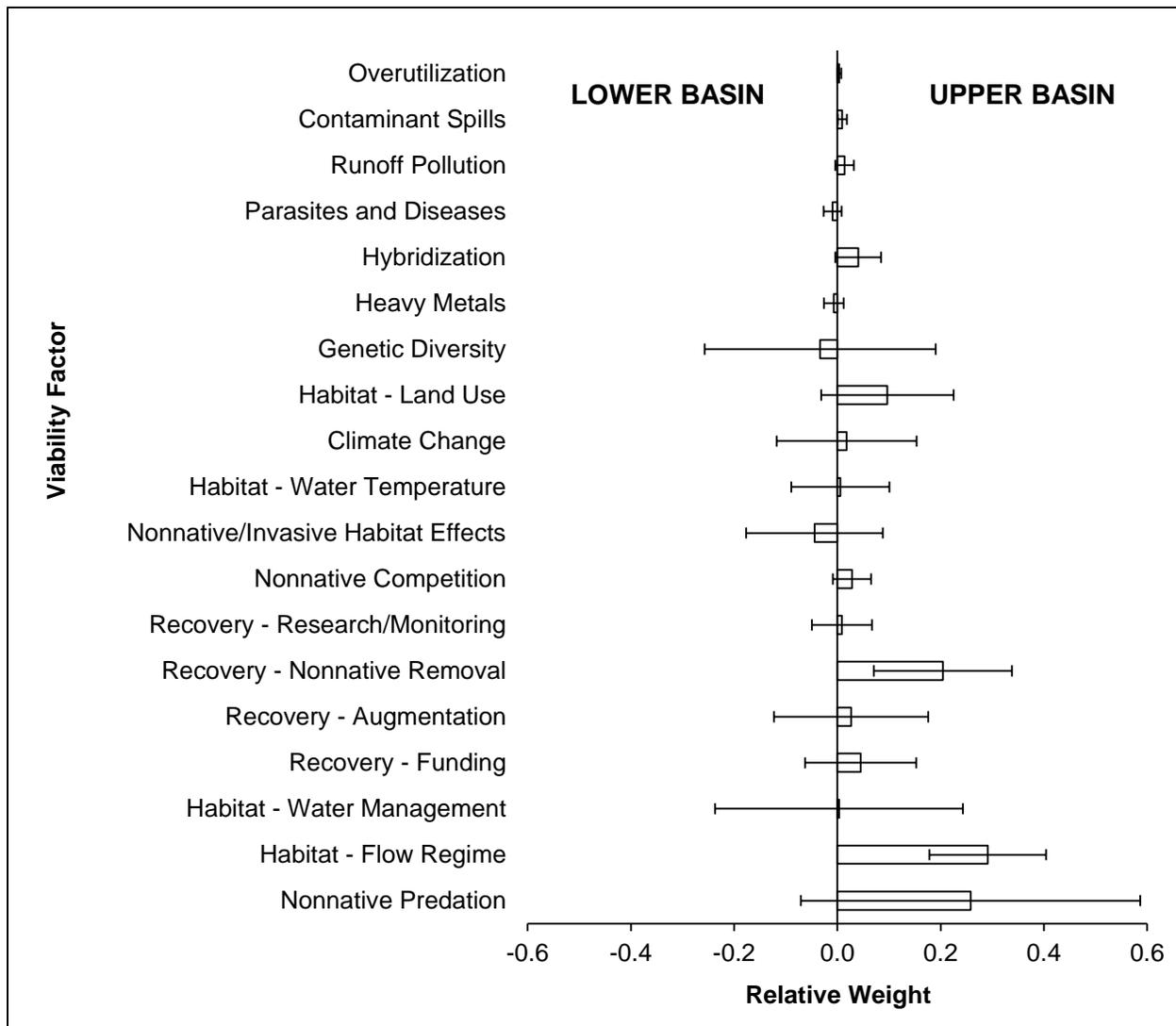


Figure 43. Mean relative weight of factors for the UCRB and LCRB in Round 3 (± 2 Standard Errors).

Looking at all of the factors in Figure 43, the only ones that do not have error bars overlapping zero are flow regime and nonnative removal; thus, participants rated these factors as being more influential in the UCRB. Factors that were perceived as a little more influential in the LCRB were habitat effects of nonnative/invasive species, genetic diversity, heavy metals, and parasites and diseases.

8.5.5 Longer-Term Viability

Finally, as mentioned earlier, participants were asked to rate whether they thought the major categories of factors would become more or less influential 30–100 years in the future. Participants were asked to rate the major factor categories (not subcategories) on a 1–5 scale with 1 representing “less influential,” 3 representing “same influence” and 5 representing “more influential.” As with the previous assessments, participants rated these factors in Round 1, provided comments regarding their ratings in Round 2, and then had the opportunity to update their ratings in Round 3 based on review of the comments provided by others. As is evident from

the error bars in Figure 44, variability decreased for all of the long-term factor ratings in Round 3 and the group averages shifted slightly. None of the factor averages changed the mean ranked order from Round 1 to Round 3.

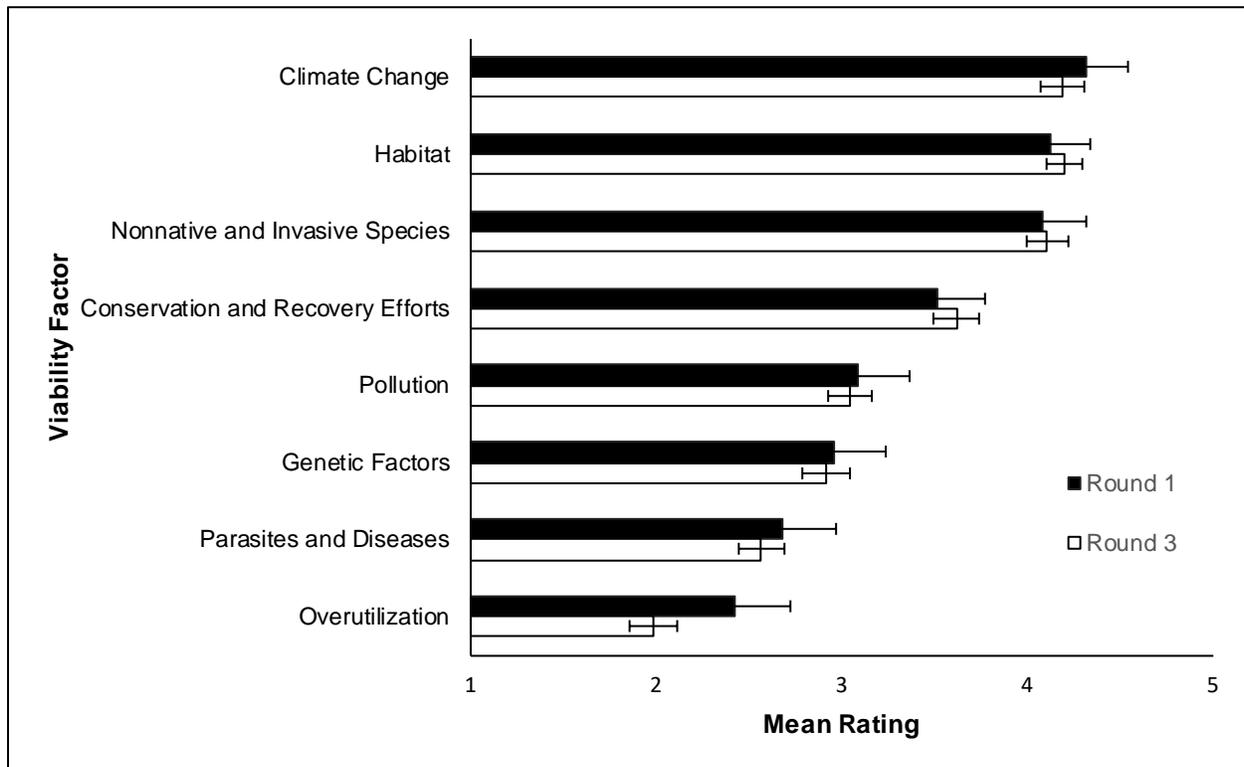


Figure 44. Mean ratings of expected change in influence on viability in 30–100 years on a 1–5 scale with 1 representing “less influential,” 3 representing “same influence,” and 5 representing “more influential” (± 2 Standard Errors).

Participants expected climate change to become more influential in the 30–100 year time frame. Referring back to ratings for the next 30 years, climate change was not expected to be as highly influential in the near term. Participants rated habitat and nonnative species as highly influential in the near term and expected these factors to become more influential in the long term, perhaps because of the relationship of these factors to climate change.

The mean rating for climate change decreased slightly from Round 1 to Round 3 (Figure 44). In Round 2 participants were asked to provide comments for any of their ratings that were one standard deviation higher or lower than the group’s average rating. The range of scores in Round 1 was from 3 to 5 on the 1–5 scale, and the group’s average rating for climate change was 4.3 with a standard deviation of 0.8. Since the highest possible scale value was 5, there were no ratings that were 1 standard deviation higher; thus only comments supporting a potentially lower rating were provided in Round 2. Those who did not rate climate change as increasingly influential in the 30–100 year period (a rating of 3) explained their rating based on the greater than expected resiliency and adaptability of razorback sucker at the present time, the broad geographic range of the species, and its apparent adaptability to historic climate variability and stochastic events through its evolutionary history. Others thought that climate change may have some positive effects such as providing warmer water where it is presently too cold or possibly

improving habitat as a result of earlier spring flows in some locations. While there was a slight decrease in the group's average rating of climate change in Round 3 (mean = 4.2, standard deviation = 0.7), the majority of participants continued to rate climate change as becoming more influential 30–100 years in the future.

Participants also expected conservation and recovery efforts to continue to influence long-term viability, having the same or an even greater influence beyond 30 years from the present. Thus, participants were not particularly optimistic that razorback sucker would become independently viable in the long term, with wild recruitment being referenced in comments as the necessary element to reduce this need.

Pollution and genetic factors were expected to have the same long-term potential influence as these factors would have in the nearer term. Parasites and diseases, and overutilization were not expected to be longer-term influences and would possibly become even less influential in the 30–100 year time frame as rated by the participants.

8.6 Discussion

In the Delphi process, there was general agreement that nonnative species constrain viability. Habitat, as influenced by flow regime and water management, was also perceived to be a top-tier influence on viability. Habitat is, of course, essential, but some participants thought that habitat was a less important influencer of viability; after Round 3 some participants continued to weight flow regime and water management less than 10. Conversely, none of the participants rated nonnative predation below this level after Round 3. Some perceived that available habitat “is what it is” (i.e., existing populations are surviving within existing habitat limitations). Thus, participants who weighted habitat as low did not expect available habitat or connectivity to be improved over what it is currently.

In the group's assessment, conservation and recovery efforts were rated sufficiently high in influence as to be considered essential to viability. It is reasonable to conclude from submitted comments that biologists working with this species do not believe, on the whole, that the species can persist without interventions continuing into the next 30 years, and likely extending beyond that time period.

Participants saw more constraints on viability in the UCRB, particularly with regard to maintaining a flow regime into the future, and the expected need to continue or increase efforts to remove nonnative fishes. Participants may have perceived LCRB populations to be more viable based on having found a recruiting population in the LCRB and knowledge that fish can be viable in lentic environments. Other recovery efforts (augmentation, research and monitoring, and program funding) were perceived to be essential in both the UCRB and LCRB.

Participants did not rate pollutants or parasites and diseases highly, and there was strong group agreement that these are not among the leading threats to razorback sucker viability. However, some felt that these factors were being underestimated by the group and should not be ignored going into the future.

Similarly, while genetic factors were not perceived as constraining viability of this species, some participants stressed that maintaining genetic diversity with the augmentation program should be continued.

Ratings and comments reflected concern and awareness of climate change and the potential effects this will have on temperature and runoff patterns. Participants were more concerned about the viability effects of climate change in the 30–100 year time frame.

It is also worth discussing comments that participants provided regarding the Delphi process itself. Some participants thought that differences in weights assigned could have been due to differences in the knowledge or confidence of less experienced biologists. In reflecting on their own weightings, some participants did say that they were not confident about their own ratings of the basin in which they had no work experience. Others said that they took the approach of weighting as many of the factors as highly as they could from the perspective of not wanting to ignore a factor and potentially see management efforts decreased in that area (i.e., taking a precautionary perspective). Finally, comments after Round 2 (when participants were able to read comments from others) indicated that there were some obvious misunderstandings of what was being rated for a given factor; examples were land use and habitat effects of nonnative and invasive species.

The Delphi process is intended to address all of these potential sources of error because participants have the opportunity to reflect on all of these methodological aspects (not just the substantive issues) when re-rating factors. Additionally, the technique is an opportunity for participants to learn from one another by taking into consideration the experiences and perspectives of their peers and having the opportunity to then modify their own ratings (Hsu and Sandford 2007; Donohoe and Needham 2009)(Hsu and Sandford 2007; Donohoe and Needham 2009).

In some cases, differences in weights assigned (high variability in weights given to the leading factors) likely reflected a genuine difference of opinion in the field as to which factor is the greater constraint on viability, or they may have reflected basin-centric concerns. However, the final dataset revealed few differences in opinion based on basin-specific work experience. Only the importance of nonnative removal efforts was weighted higher for the UCRB by all participants and by those who primarily worked there.

Much of the remaining variability after Round 3 may have been due to differences in approach to the ranking and weighting method by various participants. In the MCA ranking and weighting exercise, which started by having participants distribute 100 points among 8 major categories of factors, weights exceeding 40 points are substantively large influences because weights this high or higher leave participants with relatively few points to distribute among the other factors. Some participants distributed weights fairly evenly across the top-rated categories of factors (nonnatives, habitat, conservation, and recovery efforts), while others assigned a very high weight (in the 40–60 range) to the category that they thought was the dominant factor. For some that dominant factor was habitat, for others it was nonnatives, and for still others it was conservation and recovery efforts (referring back to Table 7, all of these categories had maximum weights of 60 in Round 1). Likewise, within major factor categories such as

conservation and recovery efforts, some participants weighted augmentation the highest among the subcategories of conservation and recovery efforts while others weighted nonnative removal or research and monitoring higher. Regardless of these idiosyncrasies, the group's average assessment was consistent from Round 1 to Round 3, with the combination of nonnative predation and habitat (as influenced by flow regime and water management) being the top-rated influences on near-term viability, with some combination of conservation and recovery efforts being perceived as essential for maintaining viable populations in the wild in the near-term, and possibly continuing to be needed in the long-term. The perceived greatest influence on long-term viability was the potential effects of climate change.

9 APPENDIX B: RANGE OF FUTURE CONDITIONS TABLE

Risk/Cons Action	Plausible Future Environmental Conditions			
	Optimistic			Pessimistic
Nonnative Predation	Nonnative predation is actively limited using a variety of techniques including exclusion, population scale efforts, mechanical removal or other novel techniques	Nonnative predation still occurs, but is partially limited by management actions like removal/exclusions	Current nonnative predators continue to limit recruitment in most habitats.	A new predator is introduced to the system and establishes reproducing populations. Expansion or greater abundance of current populations.
Habitat - Flow Regime/Habitat Connectivity	Peak flow management to connect floodplains coincident with presence of larvae expands to more locations. Flows develop and maintain habitat consistent with natural conditions Flows in the lower basin are effectively managed to prevent connections to backwater habitat, yet provide water to fill said habitat	Peak flows allow for biologically driven connections 3 in 5 years. Backwaters are managed to maintain separation from the mainstem channel.	Peak flows allow for biologically driven connections 1 in 5 years. Number or scope of backwaters is reduced because of lack of flow.	Available water is severely reduced, precluding flows to connect wetland environments. Backwater habitat is limited or eliminated by reduced flows and channelization.
Habitat - Water Management	Water management tries to mimic natural conditions, providing ecological benefit and floodplain connection.	Water management continues to incorporate strategies to mimic ecological benefits and floodplain connection.	Additional proactive and adaptive stakeholder management practices continue, but are unable to mitigate the impacts of drought and future water development Some funding remains, but at reduced levels	Water management is reduced to legally mandated actions and are unable to cope with reduced stream flows or increases in variability such that providing ecological benefit is rare. Conservation programs are no longer in place, with the exception of legally mandated actions (enforced outside of the ESA) Stocking ceases due to lack of funds
Recovery - Funding	Funding remains at current levels and adaptive management allows for more effective use, increasing funding effectiveness Stocking ceases because of wild recruitment	Funding remains at current levels and activities remain consistent with current planning efforts	Stocking/reintroduction remains, but becomes limited in scope due to lack of funds Mechanical removal of nonnative continues, but at a reduced level, where possible Development and management of backwater habitat is limited by lack of funds	Conservation programs are no longer in place, with the exception of legally mandated actions (enforced outside of the ESA) Stocking ceases due to lack of funds Nonnative management/removal ceases due to lack of funds Management of backwaters reduced because of lack of funds
Recovery - Augmentation	Nonnative populations are managed through population scale efforts, i.e. spike flows where possible	Stocking/reintroduction continues at levels deemed optimal for species support Nonnative populations are controlled using mechanical means where possible	Monitoring continues in conjunction with other efforts, but is limited in scope.	Monitoring ceases. Due to lack of funds, is handed to states in conjunction with other multi-species surveys.
Recovery - Nonnative Removal/Control	Additional backwaters are developed and actively managed to exclude nonnative fish. Monitoring expands to include population estimates and life-stage monitoring. Funds are available to determine species bottlenecks and support adaptive management	Backwaters are actively managed to exclude nonnative fish. Monitoring continues in conjunction with other efforts. Some novel research is available		
Recovery - Research/Monitoring	Nonnative fish add interference or resource competition pressures— currently unmanageable background effect			Nonnative fish use niche space that could be available for razorback sucker – currently unmanageable background effect
Nonnative Competition	Floodplains are kept free from invasive vegetation, tamarisk and Russian olive contained rangewide			Invasive vegetation expand in scope and limits access to nursery habitat
Nonnative habitat effects				
Climate Change - 30 to 100 years only	Reductions in stream flows are managed through voluntary/program efforts with little ecological degradation from current conditions			Reduced winter snowpack and late winter and early spring precipitation would likely result in an earlier and shorter runoff period.