U.S. Fish and Wildlife Service

Species Status Assessment for the Humpback Chub (*Gila cypha*)

Fish Illustration © Joseph. R. Tomelleri

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

Version 1.1

*Version 1.1 of the SSA includes an update to section 2.2 to clarify historical and current distribution through 2018. It also includes minor grammatical and formatting changes. These updates do not change the scientific analysis or conclusions within the report.

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EXECUTIVE SUMMARY

This Species Status Assessment (SSA) provides an integrated assessment of the status of the Humpback Chub (*Gila cypha*) across six populations (five extant populations and one recently considered functionally extirpated). The SSA first establishes the essential requirements of Humpback Chub by describing the species and its resource needs. Next, the SSA evaluates the current condition of the resources, ongoing conservation actions, and recent demographic information to describe the current condition of the species under existing environmental and anthropogenic factors. To assess potential future condition, the SSA forecasts the species' 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 Humpback Chub is a fish endemic to the warm-water portions of the Colorado River system of the southwestern United States. Collections show that the Humpback Chub inhabits disjunct canyon areas characterized by rocky habitat and swift currents. Humpback Chub are resilient to a variety of physical and chemical habitat conditions and tolerate a wide range of river flows at all life stages. Individuals can live up to 20 years (up to 40 years in the lower basin), reach sexual maturity around age 5, and can produce up to 2,500 eggs annually. The Humpback Chub has a variable diet, such that individuals consume a large array of food items under different river conditions.

The historical range of the species includes portions of the Colorado, Green, and Yampa rivers, but this range has been reduced through the construction of mainstem dams in canyon areas. Two of eight documented populations of Humpback Chub are extirpated because of the construction of Flaming Gorge (Hideout Canyon) and Hoover dams (Black Canyon). The species is now found as five extant populations, including four upstream of Lake Powell (Black Rocks, Westwater Canyon, Desolation/Gray canyons, and Cataract Canyon) and one downstream of Lake Powell (Grand Canyon). A sixth population in Dinosaur National Monument (DNM) is considered functionally extirpated because individuals have not been collected since 2004. Humpback Chub are now managed as two units, the 'upper basin' and 'lower basin', separated by Glen Canyon Dam.

Species Needs

The species' life cycle is described as seven life stages including spawning, eggs, larvae, age-0, juveniles, sub-adults, and adults. During each life stage, the species requires certain resource conditions to successfully move to the next stage. This SSA summarizes the following eight categories, which are considered the most important for species success:

1. Diverse rocky canyon river habitat for spawning, nursery, feeding, and shelter.
2. Suitable river flow and temperature regimes for spawning, egg incubation, larval development, and growth.
3. Adequate and reliable food supply, including aquatic and terrestrial insects, crustaceans, and plant material.
4. Habitat with few nonnative predators and competitors that allow the young to survive and recruit to maintain self-sustaining populations.
5. Suitable water quality with few contaminants and little risk of spills of petroleum products and other toxic materials.
6. Unimpeded range and connectivity that allow free movement and access to habitats necessary for all life stages.
7. Persistent populations, each with reproductive potential, recruitment, and adult survival, to ensure redundancy.
8. High genetic diversity within and across populations to maintain and ensure adaptive traits.

Current Condition

The current condition of the Humpback Chub is derived by considering the current resource conditions, ongoing management actions, and population monitoring (using intrinsic rate of growth, lambda [λ], when available). Resource conditions existing within each of the five extant upper basin populations are typically good to neutral (Table EX1; details in Table 7 in section 4.3). The upper basin populations generally have high quality rocky canyon habitat, suitable temperature, adequate food base, unimpeded connectivity, and high genetic diversity. The resources of highest concern and uncertainty are adequate flow regimes, the existence of nearby populations of nonnative fish, and intrinsic growth rates that do not indicate population growth. Management actions have been enacted over the last decade, including implementation of flow and temperature regimes (Table 4 in section 4.1) and nonnative fish removal (Table 8 in section 4.4). The extirpation of the Dinosaur National Monument population, likely caused by multiple flow related stressors over many decades after the construction of Flaming Gorge Dam, has decreased the genetic diversity in the upper basin.

In the lower basin, Humpback Chub have high quality canyon habitat, unimpeded connectivity to mainstem habitats, and high generic diversity. River flow, water temperature, food supply, and predation/competition are the key factors controlling the lower basin population (Table EX1; details in Table 7 in section 4.3). Glen Canyon Dam causes resource conditions in the lower basin to be markedly different than in the upper basin because temperature and food availability are influenced by cold water releases. Current flow releases from Glen Canyon Dam are prescribed under the Long-Term Experimental and Management Plan EIS (LTEMP EIS) and are designed to minimize impacts on canyon resources. In addition, management actions such as translocations and nonnative fish management of adult Humpback Chub are enacted to support the species (Table 9 in section 4.3).

Table EX1. A summary of the current condition of species needs for the six populations of the Humpback Chub. [For more detail descriptions of resource conditions, see Table 7 and sections 4.1 and 4.2.]. Color codes: dark green = resource condition is good, light green = fair; yellow = neutral, orange = poor; red = bad.

Resource Category	**Upper Basin**					**Lower Basin**
	Black Rocks	**Westwater Canyon**	**Desolation/ Gray canyons**	**Cataract Canyon**	**Dinosaur National Monument**	**Grand Canyon**
	Extant				Extirpated	Extant
1. Diverse rocky canyon river habitat	dark green	dark green	light green	light green	light green	dark green
2a. Suitable flow	yellow	yellow	yellow	yellow	yellow	yellow
2b. Suitable temperature	light green	light green	light green	light green	light green	light green
3. Adequate and reliable food supply	light green	light green	light green	light green	light green	orange
4. Habitat with few nonnative predators and competitors	light green	light green	yellow	light green	yellow	yellow
5. Suitable water quality	yellow	yellow	yellow	yellow	yellow	yellow
6. Unimpeded range and connectivity	light green	light green	light green	light green	light green	light green
7. Persistent populations	light green	light green	yellow	yellow	red	light green
8. High genetic diversity	light green	light green	light green	light green	red	light green

Status of Populations

Status of a population is assessed using both catch rates (catch per unit effort [CPUE]) and mark-recapture estimates to maximize data available. Adult abundances and resultant population trajectories in upper basin populations vary. Abundance estimates of adult Humpback Chub are available for individual populations within the upper basin at varying frequencies over the last 17 years (1998–2015), though not annually for any single population (Table 10). Annual abundance estimates exist from 1989–2012 in the Grand Canyon, although model differences prevent estimate comparison before and after 2008 (Table 13 and section 4.5.6).

Upper Basin Populations

- Black Rocks and Westwater Canyon show similar patterns of population trajectory, with highest estimates in early monitoring (1998–2000) that declined through 2007. Evidence suggests that since 2007, declines have potentially been arrested and populations are stabilizing, although there is uncertainty about this hypothesis.
- Abundance estimate data is insufficient to reach any reliable conclusion about the trajectory of the Desolation/Gray canyons population; however, less rigorous, catch based monitoring starting in 1985 potentially demonstrates stability over 30+ years.
- The Cataract Canyon population is small and the trajectory of adult numbers is unclear; it is likely to persist based on consistent catch of adult and young life stages.
- The Dinosaur National Monument population is currently below detection limits and is now considered functionally extirpated, with the last capture occurring in 2004.

Lower Basin Populations

- The Grand Canyon population has a large core of 11,500–12,000 adults in the Little Colorado River that has likely remained relatively stable since 2008.
- Earlier estimates documented a substantial decline around the 1990s, followed by a strong increase in the 2000s. The number of adults in the Little Colorado River core population decreased from 10,946 in 1989 to 5,021 in 2001, and then increased to 7,650 in 2008. Recent research estimates these estimates are biased low by 20-30% because models did not include skip-spawning life history trait.
- In addition to the core population in and near the Little Colorado River, there are ~250 adults and several hundred juveniles and sub-adults distributed in ~408 km of the mainstem, with evidence of reproduction in western Grand Canyon.
- The presence of Humpback Chub and evidence of successful recruitment in western Grand Canyon has important implications as an extension of the core population, or possibly as a second reproducing population in the Grand Canyon.
- Successful translocation efforts in the Little Colorado River and Havasu Creek have expanded the range of the species into new habitats. Furthermore, spawning has also been documented with translocated fish in Havasu Creek.

Evaluation of Future Condition

The future condition of the Humpback Chub is derived by considering the future resource conditions for each population. For the purpose of this SSA, the future condition is evaluated at a biologically meaningful timeframe of 16 years, which corresponds to approximately two generation times in the upper basin (<2 in the lower basin because of higher adult survival).

In order to incorporate uncertainty about predictions of future conditions, the U.S. Fish and Wildlife Service selected three possible future scenarios of ecological conditions. The Science Advisory Team then evaluated the changes in ecological condition and resultant changes in resource conditions under each scenario.

The assessment of current condition determined that stream flow and predation/competition from nonnative fish are key factors controlling upper basin populations; whereas, stream flow, water temperature, food supply, and predation/competition from nonnative fish are key factors for the lower basin population. Potential future scenarios focus on those resources. All future scenarios assume that the mean annual availability of water (snowpack and runoff) will be lower and that the risk of nonnative fish expansion is commensurately higher as well. That is, there is no indication that risks from these two stressors will decline without management intervention. The three future scenarios do include varying levels of risk from changing conditions and consider varying implementation and effectiveness of active and adaptive management.

The three scenarios selected by the Service and evaluated by the Science Advisory Team are:

- Scenario 1 [Environmental Stressors Increase and New or Discretionary Extralegal Actions are Eliminated]- This scenario includes elimination of some active and adaptive actions, and a reduction in voluntary management actions for the species, such that many stakeholder actions are no longer in place to mitigate future conditions including decreased water availability, future water development, or nonnative fish. Conservation actions codified under binding agreements (NEPA, Section 7) would continue. For example, instream flows would not be legally protected any more than they are today (e.g. RODs, PBOs remain in effect), some voluntary flow management actions would diminish, and nonnative fish management would not continue in the upper basin. In the lower basin, water management, nonnative fish control, and other actions would remain consistent with the current level of effort prescribed by various RODs and Section 7 consultations, but no new or adaptive actions would take place. Although a greater proportion of actions in the lower basin are legally required, in this scenario it is expected that management actions are not adaptive or effective and unable to respond to the impacts from various stressors causing population declines of Humpback Chub in both basins.

- Scenario 2 [Legally Mandated Management Actions and Additional Adaptive Management Actions Occur, but are Ineffective] - In addition to minimum actions required under Scenario 1, this scenario provides additional proactive and adaptive stakeholder management practices into the future; however, these actions are unable to mitigate impacts of drought, future water development, nonnative fishes, or other threats. For example, water operations cannot provide adequate flows or temperatures in Humpback Chub habitats because drought or other factors have decreased water supply, or nonnative fish colonize Humpback Chub habitat in high densities despite stakeholder action. In this scenario, it is expected that management actions respond to the impacts from various stressors but are not effective to prevent Humpback Chub declines.

- Scenario 3 [Legally Mandated Management Actions and Adaptive Management Actions Occur, and Are Effective] - In addition to minimum actions required under Scenario 1, this scenario provides additional proactive and adaptive stakeholder agencies' management practices into the future for the species, and these actions are sufficient to mitigate impacts of drought, future water development, nonnative fishes, or other threats. For example, water operations have the flexibility to provide adequate flows and temperatures to and nonnative fish do not colonize or are effectively managed in Humpback Chub habitat. In this scenario, it is expected that management actions respond to the impacts from various stressors causing population declines, and are adequate to stabilize and increase Humpback Chub populations.

Potential Future Conditions

For each of the potential future scenarios, the overall effect expected to occur within each population is described in sections 5.3.1, 5.3.2, and 5.3.3. Conditions of species needs are summarized in Table EX2, with details provided in Tables 16, 17 and 18 for Scenarios 1, 2, and 3 respectfully. Conditions under scenario 1 are largely poor and bad and do not support Humpback Chub needs. Conditions improve greatly in scenario 2, although flow, nonnative fish management, and food (in the Grand Canyon) are still not sufficient. Under scenario 3 conditions improve to provide Humpback Chub with conditions that are sufficient for the species.

Under scenario 1, the increased threat of reduced water availability and existing nonnative fish populations are not mitigated with any additional actions that are not currently legally mandated. In the upper basin rocky canyon habitat, suitable temperature, adequate food supply, and connectivity of populations are largely still provided, and catastrophic low flows are prevented through the operation of Bureau of Reclamation facilities under existing RODs. However, the lack of water supply and adaptive flow management increases frequency of drier hydrologies, diminishing habitat quality for Humpback Chub. Even more consequentially, drier hydrologies and lack of nonnative fish removal likely allows established nonnatives, especially Smallmouth Bass, to expand into Humpback Chub areas such as Desolation / Gray canyons and Black Rocks. Under all of these stressors, it is expected that at least one upper basin population would become extirpated and others would decrease in abundance quickly, thus also straining the genetic diversity of the upper basin. In the lower basin, the physical habitat will remain intact and flow regimes are already in place. However, temperature, food supply, and nonnative fish conditions would worsen for Humpback Chub. Predation/competition by Rainbow Trout and Brown Trout is likely to continue and other warm-water species may increase in impact. Effects of groundwater pumping are largely unknown, but could have dire consequences for the core Little Colorado River population.

Under scenario 1, conditions in both the upper and lower basin are expected to strain the resiliency of Humpback Chub with poor resources conditions. The upper basin will likely see dramatic population declines, will likely lose another population to extirpation, and cannot re-establish the Dinosaur National Monument population. The core lower basin population in the Little Colorado River is expected to continue to reproduce and recruit annually, but be less resilient than it is currently. The current population size protects the core population from a variety of potential threats.

Under scenario 2, the increased threat of reduced water availability and existing nonnative fish populations are mitigated with additional actions but those actions are not effective. In the upper basin, rocky canyon habitat, suitable temperature, adequate food supply, and connectivity of populations are largely still provided, and catastrophic low flows are prevented. Under existing RODs, the Bureau of Reclamation provides some adequate flows and with minor increases in frequency of drier hydrologies, habitat quality for Humpback Chub diminishes. Ineffective nonnative fish removal cannot prevent established nonnative fish, especially Smallmouth Bass, to slowly expand into Humpback Chub areas such as Desolation / Gray canyons. Upper basin populations slowly decrease in abundance, putting the genetic diversity of the upper basin at risk if multiple populations within a genetic grouping are simultaneously nearing extirpation. In the lower basin the physical habitat will remain intact and flow regimes are already in place. However, temperature, food supply, and nonnative fish conditions could worsen for Humpback Chub. Implementing actions to improve food production and prevent expansion of nonnative would be ineffective. Predation/competition by Rainbow Trout and Brown Trout is likely to continue. Genetic diversity is expected to persist, and a second reproduction center in the western Grand Canyon may occur under this scenario.

Under scenario 2, conditions in the upper and lower basin slowly decrease in quality because additional and adaptive stakeholder actions are insufficient to mitigate the impacts. For example, in the upper basin, nonnative fish control is implemented, but does not prevent expansion of Smallmouth Bass. In the lower basin, food supply may be limited and additional tools to manage nonnative fish are not effective. In the upper basin populations are likely to steadily decline because of limited recruitment and unsuccessful attempts to re-establish the Dinosaur National Monument population. In the lower basin the core Little Colorado River population continues to recruit, but areas outside may be reduced.

Table EX2. A summary of the future condition of species needs for the six populations of the Humpback Chub under three potential future scenarios. [For more detailed descriptions of resource conditions, see Table 16, 17, and 18 and sections 5.3.1, 5.3.2, and 5.3.3.] Color codes: dark green = resource condition is good, light green = fair; yellow = neutral, orange = poor; red = bad.

Resource Category	Scenario 1: Environmental Stressors Increase and New or Discretionary Extralegal Actions are Eliminated						Scenario 2: Legally Mandated Management Actions and Additional Adaptive Management Actions Occur, but are Ineffective						Scenario 3: Legally Mandated Management Actions and Adaptive Management Actions Occur, and Are Effective					
	Details Found in Table 16						Details Found in Table 17						Details Found in Table 18					
	BR	WW	DG	CC	DNM	GC	BR	WW	DG	CC	DNM	GC	BR	WW	DG	CC	DNM	GC
1. Diverse rocky canyon river habitat	dark green	dark green	light green	light green	light green	dark green	dark green	dark green	light green	light green	light green	dark green	dark green	dark green	light green	light green	light green	dark green
2a. Suitable flow	orange	orange	orange	yellow	red	yellow	yellow	yellow	yellow	light green	orange	yellow	light green	light green	light green	light green	yellow	yellow
2b. Suitable temperature	yellow	yellow	yellow	yellow	yellow	light green	light green	light green	light green	light green	light green	light green	light green	light green	light green	light green	light green	light green
3. Adequate and reliable food supply	light green	light green	light green	light green	light green	red	dark green	dark green	dark green	dark green	dark green	yellow	dark green	dark green	dark green	dark green	dark green	light green
4. Habitat with few nonnative predators and competitors	red	orange	red	yellow	red	orange	yellow	yellow	orange	light green	orange	yellow	light green	light green	yellow	light green	yellow	yellow
5. Suitable water quality	orange	orange	orange	orange	orange	orange	yellow	yellow	yellow	yellow	yellow	yellow	yellow	yellow	yellow	yellow	yellow	yellow
6. Unimpeded range and connectivity	light green	light green	yellow	yellow	orange	light green	dark green	dark green	dark green	dark green	yellow	light green	dark green	dark green	dark green	dark green	yellow	dark green
7. Persistent populations	red	red	red	red	red	light green	yellow	yellow	orange	orange	red	light green	dark green	dark green	light green	dark green	yellow	dark green
8. High genetic diversity	red	red	red	red	red	yellow	yellow	yellow	yellow	yellow	red	light green	dark green	dark green	light green	light green	yellow	dark green

Under scenario 3, the increased threat of reduced water availability and existing nonnative fish populations are mitigated with additional actions that successfully improve Humpback Chub condition. In the upper basin, rocky canyon habitat, suitable temperature, adequate food supply, and connectivity of populations are provided, and sufficient inter- and intra-annual flow variability is provided under existing RODs. Nonnative fish removal suppresses existing population expansions, especially for Smallmouth Bass. Upper basin populations slowly stabilize or increase in abundance with improved recruitment. The genetic diversity of the upper basin is maintained. In the lower basin the physical habitat will remain intact and flow regimes are already in place. Temperature, food supply, and nonnative fish conditions could improve for Humpback Chub with implementation of new actions. Although predation/competition by Rainbow Trout and Brown Trout is likely to continue, impacts do not alter the demographics of Humpback Chub. Genetic diversity is expected to persist, and a second reproduction center in the western Grand Canyon likely occurs under this scenario.

Under scenario 3, conditions in the upper and lower basin that have improved Humpback Chub condition over the past decade or more are continued, are effective, and are expanded as needed. In the upper basin, nonnative fish management prevents expansion of Smallmouth Bass and supplies adequate flow regimes for strong recruitment. In the lower basin, food supply, temperature regime, and nonnative fish are appropriately managed with additional tools. Persistent populations in the upper basin become stable or increase and the Dinosaur National Monument population is potentially re-established. In the lower basin, the core Little Colorado River population continues to be stable and Humpback Chub expand its range within the Grand Canyon.

Species Viability

To characterize species viability, the principles of resiliency, redundancy, and representation are used to summarize resource conditions, biological traits, population demographics, and genetic diversity. Resiliency describes the ability of individuals and populations to withstand environmental or demographic stochasticity. Redundancy describes the ability of populations to withstand catastrophic events in a way that spreads risk and minimizes potential loss of the species. Redundancy is characterized as having multiple, resilient populations distributed across the range of the species. 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.

Humpback chub have many traits that enable individuals to be resilient in the face of environmental or demographic stochasticity including long life span, high reproductive potential, use of habitats and turbidity that are arduous to other species, adaptation to a wide variety of flow and thermal regimes, and a variable omnivorous diet. Population resiliency is demonstrated by a variety of traits including persistence of small populations (Cataract Canyon), population increases over many years of decline (Grand Canyon), increases after translocations (Havasu Creek), and potential stabilization of declines (Black Rocks and

Westwater Canyon). In addition, the current population size of the Grand Canyon protects it from a variety of potential threats.

The current distribution of the Humpback Chub provides a sufficient level of redundancy, albeit at a near-minimal level. Existing populations have independent susceptibility to threats by occurring in different river basins. New populations are being discovered (western Grand Canyon) or established (Havasu Creek) in the lower basin, and are being considered (Dinosaur National Monument) in the upper basin. This redundancy also assists with representation, as all genetic diversity of the species occurs in multiple populations, except the very large Grand Canyon population. In the upper basin, exchange of individuals is sufficient to ensure genetic diversity.

Considering these individual and population traits, the current condition of resource needs, and the potential future condition of resource needs, the Science Advisory Team evaluated expected condition of resiliency, redundancy, and representation at the biologically meaningful timeframe under the three potential future scenarios described by the U.S. Fish and Wildlife Service (summarized in Table EX3, with detailed conditions in Tables 19 and 20). In the upper basin, scenario 1 provides bad conditions for Humpback Chub, while scenario 2 provides poor to neutral conditions, and scenario 3 provides fair conditions that support the species. In the lower basin, scenario 1 provides poor resiliency and neutral redundancy, but all other conditions in the lower basin are fair to good in all three scenarios. This demonstrates that the resiliency, redundancy, and representation of the five extant upper basin populations are much more tenuous and impacted by management effectiveness than the lower basin population.

Table EX3. A summary of resiliency, redundancy and representation under the three future scenarios presented above for the upper and lower basins.[For more detail descriptions see Tables 19 and 20 and section 6.2] Color codes: dark green = good, light green = fair; yellow = neutral, orange = poor; red = bad.

		Resiliency	Redundancy	Representation
Upper Basin	S1			
	S2			
	S3			
Lower Basin	S1			
	S2			
	S3			

It is apparent that the species is expected to be fairly well represented and resilient in the future under scenarios 2 and 3. Redundancy is less certain, but primarily because of the potential to see declines in upper basin populations under ineffective management actions. If management actions can prevent a loss of an additional upper basin population, or re-establish the Dinosaur National Monument population (Scenario 3), conditions will be sufficient for the species.

Using these conclusions to consider species viability, species experts and the Service agree that based on the best available information, species viability is more tenuous in the upper basin than in the lower basin. One of the largest threats to the Humpback Chub, that of nonnative fish invasions, increases dramatically with time as invasions are difficult to predict – both in timing and extent of damage. In both scenarios 1 and 2, the potential effects of nonnative predation or competition indicate that the species may suffer declines within the foreseeable future. Scenario 3 is defined by the ability of management actions to react to and reduce the threat from these invasions, and thus shows species viability continuing on its current trend or possibly increasing over time.

Ongoing and future management could be sufficient to offset threats and promote survival and recruitment for 30 years, but some uncertainty surrounds future management activities. Although many conservation efforts in the Lower Basin are guaranteed for more than 50 years in the future, efforts in the Upper Basin have not been contracted beyond 2023 or funded beyond 2019. Uncertainty remains regarding current population trajectories of Humpback Chub, densities of nonnative predators in the upper basin, and risk associated with future conditions throughout the basin.

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1.0 INTRODUCTION

1.1 Overview and Report Organization

This Species Status Assessment (SSA) provides a consolidated description of the biological status of the endangered Humpback Chub (*Gila cypha*). This document is based on the best available scientific information and was prepared in accordance with the Species Status Assessment Framework of the U.S. Fish and Wildlife Service (2016a; Service). This SSA may be used by the Service to inform decisions about the species related to the Endangered Species Act (ESA). The ultimate goal of the SSA is to provide a clear description of species' needs, current condition, and response to probable future condition in order for the Service to determine the near-term and long-term viability of the species. This SSA does not replace or supplant species recovery plans or species status reviews.

This SSA is organized in the following sections with corresponding content:

- **1.0 Introduction:** report organization and description of species status assessment framework.
- **2.0 Species Overview:** species description and taxonomy, range and distribution, evolutionary history and genetics, and listing status.
- **3.0 Species Needs:** life history and resource needs that are most important to the species by life stage.
- **4.0 Current Condition:** controlling factors by life stage, condition of populations, ongoing management actions, and resource relationships that describe the current condition of the species.
- **5.0 Future Condition:** projection of populations under three future probable condition scenarios, and benefits of future conservation actions.
- **6.0 Species Viability:** characterization of species viability in terms of resiliency, redundancy, and representation.

A list of measures, acronyms, and abbreviations used in this document is provided in Appendix A. An assessment of future flow and temperature conditions is provided in Appendix B.

1.2 Species Status Assessment Framework

A Species Status Assessment provides a consistent, scientifically-based and conservation-focused assessment of the biological status of a species (USFWS 2016a). The SSA involves three assessment stages (Figure 1):

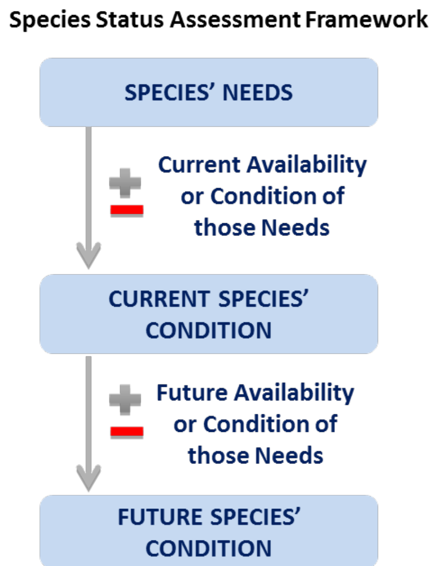

Figure 1. The Species Status Assessment Framework's three basic stages (USFWS 2016a).

1. **Species' Needs.** The first stage is a compilation of the best available biological information on the species (taxonomy, life history, and habitat) and its ecological needs at the individual, population, and species levels based on how environmental factors are understood to act on the species and its habitat.
2. **Current Condition.** The second stage describes the current condition of the species' habitat and demographics, and the probable explanations for past and ongoing changes in abundance and distribution within the species' ecological settings (i.e., areas representative of the geographic, genetic, or life history variation across the species' range).
3. **Future Condition.** The last stage forecasts the species' response to probable future scenarios of environmental conditions and conservation efforts. As a result, the SSA characterizes species' ability to sustain populations in the wild over time (viability) based on the best scientific understanding of current and future abundance and distribution within the species' ecological settings.

This SSA is not a decision document. It is an analytical tool used by the Service for summarizing biological and ecological information that can help inform a variety of decisions and activities under the ESA, including recovery planning, 5-year status reviews, inter-agency consultations, and species reclassifications (Figure 2).

Conducting a Species Status Assessment involves compiling and analyzing the best available scientific information for the species. The SSA is a living, stand-alone, science-based document, independent of the application of policy or regulation. It provides foundational biological information, articulates key uncertainties, and ultimately characterizes the species' current and future condition and viability under various scenarios and timeframes.

This SSA was done for the Humpback Chub in advance of the preparation of a species recovery plan and 5-year status review. The SSA process also provides a framework for development of recovery criteria in the species recovery plan.

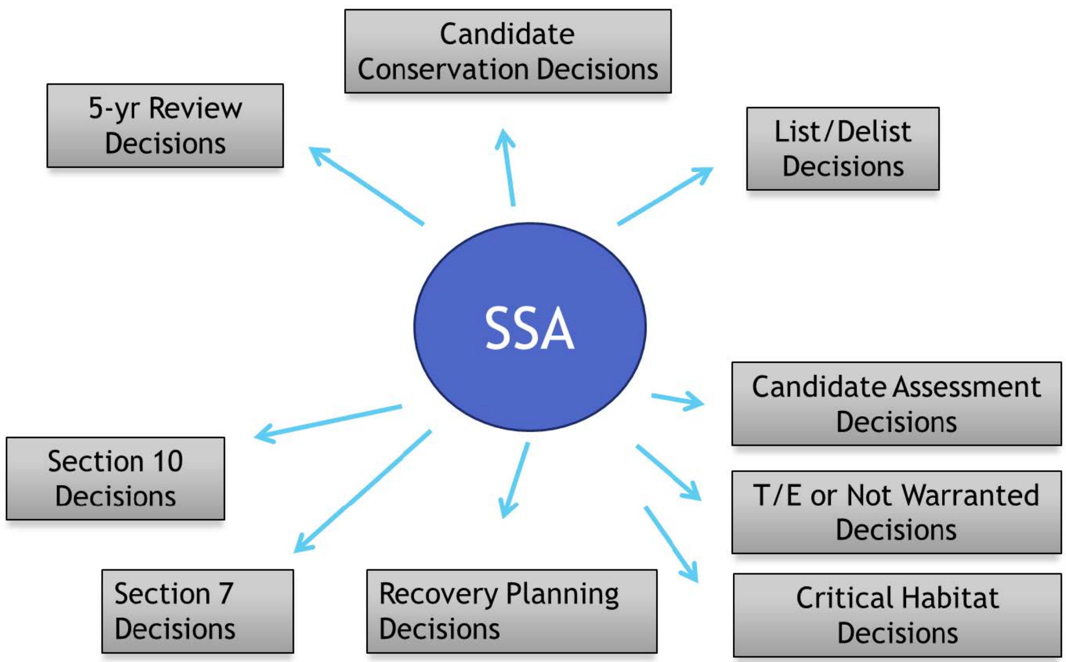

Figure 2. The Species Status Assessment Framework supports Endangered Species Act decisions (USFWS 2016a).

Throughout this SSA, the principles of resiliency, redundancy, and representation (3 R's) are used to characterize species viability and to ensure that the SSA is comprehensive and biologically sound. The 3 R's have a relationship to individuals, populations, and the species, as portrayed in Figure 3. The following is a description of the 3 R's (USFWS 2016a):

- **Resiliency** describes the ability of a species to withstand stochastic disturbance. Resiliency is positively related to population size and growth rate and may be influenced by connectivity among populations. Generally speaking, populations need abundant individuals within habitat patches of adequate area and quality to maintain survival and reproduction in spite of disturbance.
- **Redundancy** describes the ability of a species to withstand catastrophic events; it's about spreading risk among multiple populations to minimize the potential loss of the species from catastrophic events. Redundancy is characterized by having multiple, resilient populations distributed within the species' ecological

settings and across the species' range. It can be measured by population number, resiliency, spatial extent, and degree of connectivity. Our analysis explores the influence of the number, distribution, and connectivity of populations on the species' ability to withstand catastrophic events (e.g., rescue effect).

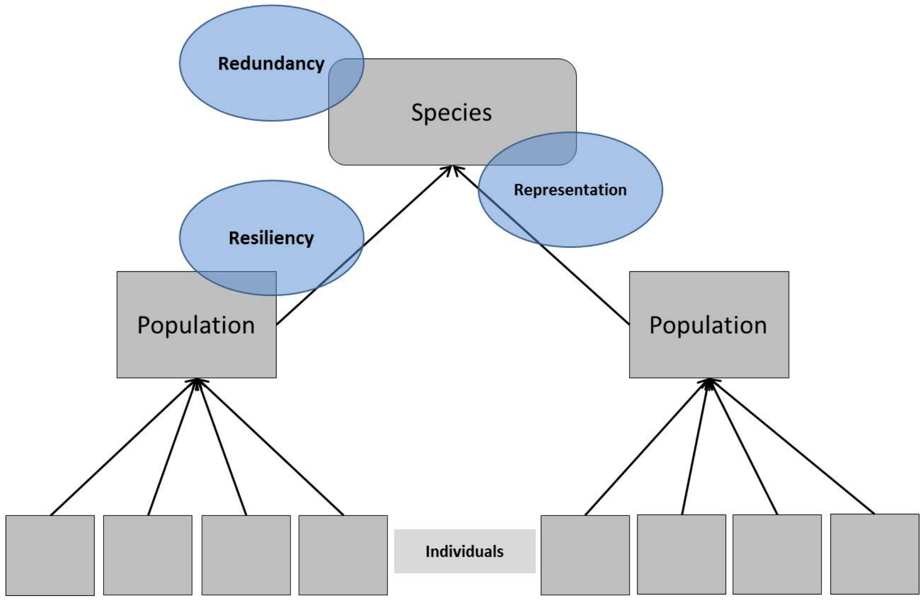

Figure 3. Relationship of resilience, redundancy, and representation at the individual, population, and species levels. Resiliency is measured at the population level, representation is measured at the species and, possibly, population level, and redundancy is measured at the species level. In practice the 3Rs are interrelated – resiliency supports redundancy, representation supports resiliency, etc. (USFWS 2016a).

- **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, the gene diversity, heterozygosity or alleles per locus. Our analysis explores the relationship between the species life history and the influence of genetic and ecological diversity and the species ability to adapt to changing environmental conditions over time. The analysis identifies areas representing important geographic, genetic, or life history variation (i.e., the species' ecological settings).

2.0 SPECIES OVERVIEW

2.1 Description and Taxonomy

The Humpback Chub was described from a fish caught by angling in 1933 near Bright Angel Creek, a tributary of the Colorado River in Grand Canyon (Miller 1946), making it one of the last large fish species to be described in North American (Service 1979). The species is a member of the minnow family that attains a total length (TL) of ~480 mm and a weight of ~1.2 kg (Valdez and Ryel 1997). Juveniles have cylindrical bodies with a greenish back, silvery sides, and a whitish belly. Adults have an enlarged nuchal hump that rises abruptly behind the head and a laterally-compressed body that is fusiform and tapered toward a slender tail (Figure 4). The back and sides are grayish green fading to a whitish belly. The scales are small and deeply embedded, sparse toward the back, and absent from the nuchal hump and belly. The fins are large and falcate and the tail is deeply forked.

Spawning adults develop small protuberances or tubercles on the head and paired fins; and the gill coverings, paired fins, anal fin, and belly become tinged with orange. Dorsal and anal fins typically have 9 and 10 principal rays, respectively, and the pharyngeal arch is small with a short lower ramus and deciduous teeth in a typical pattern of 2,5–4,2 (Miller 1946). Examination of otoliths (Hendrickson 1993) and recapture data indicate that Humpback Chub frequently reach an age of over 20 years, with longevity of ~40 years (Coggins et al. 2006; STReaMS July, 2016).

Figure 4. Adult Humpback Chub in spawning condition (Photo courtesy of U.S. Geological Survey).

2.2 Range and Distribution

The Humpback Chub is a warm-water riverine fish species endemic to the Colorado River System of the southwestern United States. The exact historical range of the species is uncertain because the difficulty sampling its canyon habitats made it largely inaccessible to early researchers (Service 1979). In fact, until the 1950s the Humpback Chub was only known from the Grand Canyon; range descriptions of new populations continued into the 1980s (Valdez 1990). Because of this lack of historical fish sampling data, the best inferences for historical range can be made using paleontological evidence, reports and photographs by early explorers, and historical fish collections. Historical and recent collections have documented the species in the states of Arizona, Colorado, Utah, and Wyoming (Figure 5).

The Service estimated the historical range of the species was 2,180 km of river (1,354.6 mi) when designating critical habitat for the humpback chub in 1990, but recognized the historical distribution of the species was not well known (Final Rule Determination of Critical Habitat; 59 Fed. Reg. 13374). This estimated historical range includes intervening river reaches between canyon habitats in the upper basin that were likely migratory, but not residential areas for the species, and thus inflates the expected historical range of the species. Historical collections show that the Humpback Chub was found in disjunct canyon areas, reflective of contemporary collections and distribution (USFWS 2002). Therefore, the species' historical range can be generally described as canyon-bound, warm-water reaches within the Colorado and Green River subbasins, between the Colorado River from the Black Canyon near present-day Hoover Dam, AZ/NV, upstream to Debeque Canyon, CO; the Green River to the Blacks Fork River, WY; and the Yampa River through Cross Mountain Canyon, CO (Kolb and Kolb 1914; Miller 1946, 1955; McDonald and Dotson 1960; Smith 1960; Holden 1973).

Specific historical evidence indicates that the species occurred in eight locations, six in the upper basin and two in the lower basin (Table 1; Figure 5). Using best expert judgment, personal communications, and published reports, we estimated the range of humpback chub in these eight populations before dams and reservoirs were constructed. Using this information, the best estimate of the historical range of the species is 768.9 km (477.8 mi) of river (Table 1). The most widespread population is the Grand Canyon, where canyon-bound habitat is continuous and humpback chub have been documented throughout the canyon. Small enclave groups of fish have been documented in localized canyon-like reaches of the upper basin, such as Beavertail Bend and Elephant Canyon in the upper Colorado River (Valdez 1990); and the Little Snake River, a tributary of the Yampa River in Colorado (Wick et al. 1991), but resident populations cannot be confirmed in these locations.

The species is currently found in five locations, including four populations in the upper basin (Black Rocks, Westwater Canyon, Desolation/Gray canyons, and Cataract Canyon), and one population in the lower basin (Grand Canyon). Each the remaining populations consists of a discrete, geographically separate group of fish, with a few individuals moving among populations at a decadal scale, based on genetic evidence (Douglas and Douglas 2007). One population in the upper basin (Hideout Canyon) and one in the lower basin (Black Canyon) were inundated by reservoirs and subsequently extirpated. A third population (Dinosaur National Monument, comprised of Yampa and Whirlpool canyons) was extirpated more recently around 2006.

Long-term sampling indicates extant populations have varying levels range reductions compared to historical distribution, although the exact range of humpback chub prior to the 1980s is not well documented (see references in Table 1). Range reduction in the Cataract Canyon population is the result of inundation of habitat by Lake Powell. The inundation of western Grand Canyon by Lake Mead also caused range reduction, although a declining elevations of Lake Mead has recently exposed this habitat and humpback chub have returned. Range reductions in Westwater and Desolation & Gray Canyons likely represent a contraction of humpback chub range as nonnative species began to inhabit reaches above and below canyon reaches. The Black Rocks population has not contracted in range.

Today, the five extant populations occupy approximately 525.3 km (326.4 mi) of river, or 68% of the historical 768.9 km (477.8 mi) (Table 1). In the upper basin, the species occurs in 33% of its historical habitat, largely the result of the extirpation of the Dinosaur National Monument population and contraction of the Cataract Canyon population. In the lower basin, the species occurs in 94% of its historical habitat because it is currently found throughout the Grand Canyon.

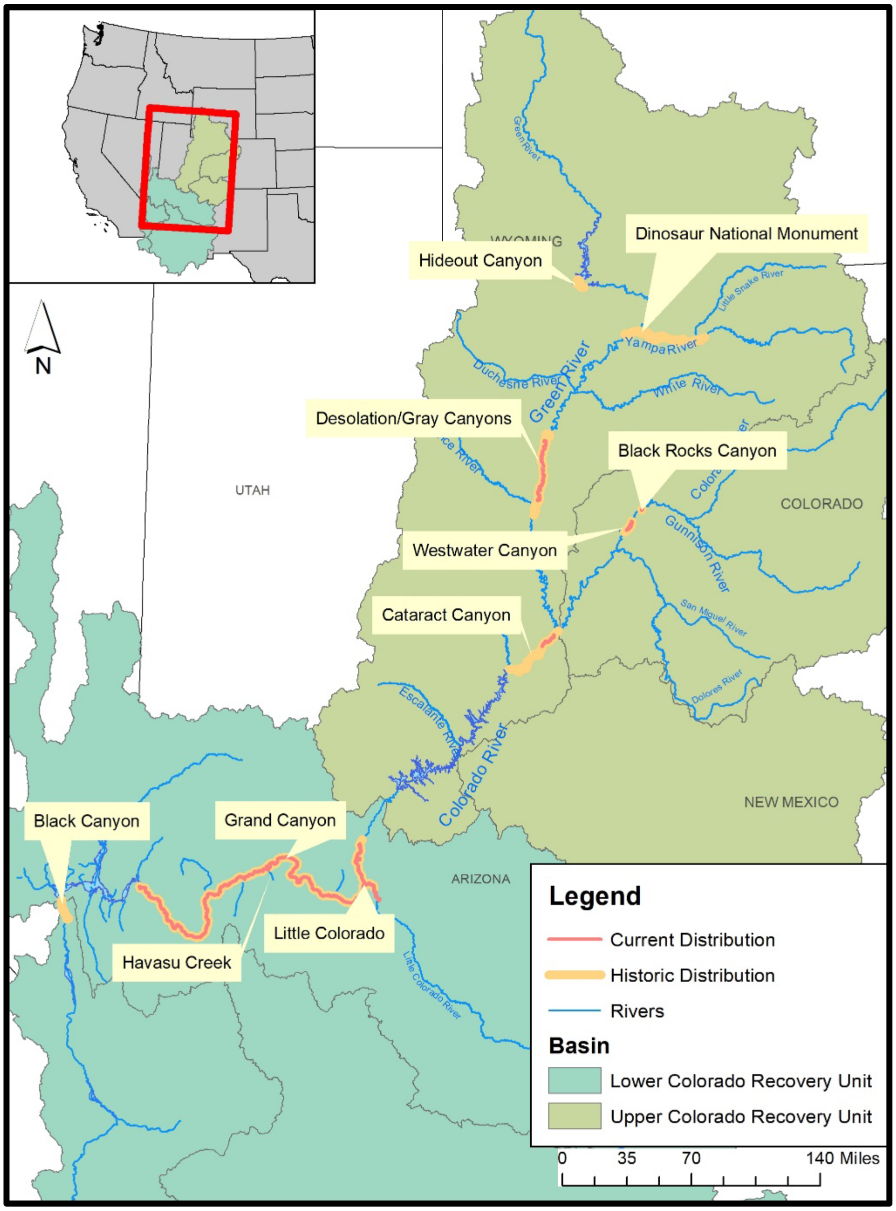

Figure 5. Current and historical distribution of the Humpback Chub.

Table 1. Estimated historical and present distribution of Humpback Chub populations. River Reaches with asterisks (*) are new translocation areas and are not considered in calculation of historical habitat.

Population	Historical		Present		Present Distribution			Reference
	Miles	Km	Miles	Km	Percent of historical	Begin River Mile	End River Mile	
Upper Basin								
1. Black Rocks, upper Colorado River, CO	1.0	1.6	1.0	1.6	100%	135.5	136.5	Kidd 1977; Valdez et al. 1982; Francis et al. 2016
2. Westwater Canyon, upper Colorado River, UT	10.0	16.1	8.4	13.5	84%	116.4	124.8	Valdez et al. 1982; Hines et al. 2016
3. Desolation/Gray canyons, Green River, UT	68.0	109.4	47.1	75.8	69%	142.9	190	Holden and Stalnaker 1970; Moretti et al. 1989; Badame 2012
4. Cataract Canyon, upper Colorado River, UT	38.9	62.6	11.0	17.7	28%	-14.5[d]	-3.5[d]	Valdez 1990; Badame 2008
5. Dinosaur National Monument[a]								
5a. Yampa Canyon, Yampa River, CO	60.0	96.5	0	0	-			Tyus 1998; Finney 2006
5b. Whirlpool Canyon, Green River, CO/UT	15.0	24.1	0	0	-			Vanicek 1967; Tyus et al. 1982; Tyus 1998; Bestgen & Irving 2006
6. Hideout Canyon, Green River, WY	10.0	16.1	0	0.0	-			McDonald and Dotson 1960; Smith 1960; Holden 1973
Upper Basin Subtotals:	202.9	326.4	67.5	108.6	33%			
Lower Basin:								
7. Grand Canyon, Lower Colorado River, AZ	253.5	408.0	250.5	403.1	99%	30	280.5	Valdez and Ryel 1995; Van Haverbeke et al. 2017
7a. Little Colorado River, AZ	8.4	13.6	8.4	13.6	100%	0	8.4	Kolb and Kolb 1914; Van Haverbeke et al. 2013
7b. Little Colorado River, AZ[b] —Above Chute Falls	0	0.0	2.7*	4.4*	-	8.4	11.1	Stone 2016
7c. Havasu Creek, AZ[c]	0	0	3.5*	5.6*	-			Trammell et al. 2012; Nelson et al. 2016
8. Black Canyon, Lower Colorado River, AZ/NV	13	20.9	0	0.0	-			Miller 1955
Lower Basin Subtotals:	274.9	442.5	258.9	416.7	94%			
Totals:	477.8	768.9	326.4	525.3	68%			

[a] This population is below detection limits and is now considered functionally extirpated. The last collection of humpback chub in this population were in the Yampa River in 2004 and in the Green River in 2006.

[b] A total of 2,971 juvenile Humpback Chub were translocated from the lower LCR to above Chute Falls (RK 13.57) during 2003–2015 (see section 4.5, Table 15).

c A total of 1,650 juvenile Humpback Chub were translocated from the LCR to lower Havasu Creek during 2011–2015 (see section 4.5, Table 15).

[d] Negative river miles indicate miles below the confluence between the Colorado and Green Rivers.

2.3 Evolutionary History

An overview of the evolutionary history of the Humpback Chub (*Gila cypha*) helps to inform contemporary population connectivity and exchange of individuals among populations. Systematic studies show that the Humpback Chub evolved as a species in canyons of northern Arizona (Grand Canyon) 3–5 million years ago (Holden 1968; Smith et al. 1979), during mid-Pliocene and early Pleistocene epochs, as the Colorado River was cutting through the Kaibab upwarp of the Colorado Plateau and joining the upper and lower basins (Bills et al. 2016). The Roundtail Chub (*Gila robusta*) and Bonytail (*Gila elegans*) appear to have evolved in the upper basin, but the Humpback Chub arose in response to the conditions of large erosive riverine habitats as a specialized derivative of the Roundtail Chub, as supported by allozyme and mitochondrial DNA linkages (Dowling and DeMarais 1993; Starnes 1995). It was suggested when the species was described that the enlarged nuchal hump, leathery skin, small embedded scales, torpedo-shaped body, and large falcate fins of the Humpback Chub are specialized adaptations to the swift, turbulent, silt-laden conditions of the Colorado River in Grand Canyon (Miller 1946).

Over time, the Humpback Chub dispersed from the Grand Canyon to other large canyon habitats of the Colorado River System, occupying primarily major rivers and large tributaries. Surrounding highlands in the Rocky Mountains underwent significant Pleistocene glaciation in the last 2 million years, and melting of these glaciers caused the Colorado River to flood and expand (Blakey and Ranney 2008), creating additional habitats and avenues for fish dispersal. Movement of Humpback Chub into the upper basin may have also been aided by the formation of large reservoirs created by lava flows that dammed the Colorado River in western Grand Canyon. At least 13 major lava dams have impounded the river in the last 1.8 million years, with the most recent ~400,000 years ago (Duffield 1997). The largest of these dams was at present-day Lava Falls Rapid (RM 179). At an estimated height of 610 m, this lava dam created a reservoir larger than modern-day Lake Powell (Glen Canyon Dam is 220 m high) that could have persisted for 3,000 years (Hamblin 1990). Shoreline deposits indicate that it extended as far upstream as modern-day Moab, UT, enabling fish to more easily disperse into the upper basin and eventually settle in isolated canyon reaches.

Paleontological evidence indicates that the ichthyofauna of the historical river and these ancient reservoirs was similar to the more recent native fish assemblage and consisted of 10 to 15 species—mostly cyprinids (minnows) and catostomids (suckers) (Miller 1959; Minckley et al. 1986). Remains of the Humpback Chub from high-elevation deposits of the Quaternary period (last 2.6 million years) indicate that the species was present when large portions of eastern Grand Canyon and Marble Canyon were inundated by the lava dam reservoirs (Miller 1955; Miller and Smith 1984). Survival strategies during this period are unclear, but the Humpback Chub apparently persisted in these ancient reservoirs, whereas, the species does not live in modern-day reservoirs, possibly because of the large number of contemporary nonnative predators that were otherwise historically absent.

The current distribution of the Humpback Chub in the upper basin, as disjunct canyon-confined populations, can be plausibly explained as a consequence of speciation in the rigorous conditions of the Grand Canyon, followed by long-term dispersal to present-day habitats with similar geomorphic and hydraulic features. Although the Humpback Chub is a comparatively weak swimmer (Bulkley et al. 1982) and is not known as a long-distance migrator, its ability to make limited movements through swift currents (Paukert et al. 2006) has enabled the species to disperse locally to find suitable habitat under changing conditions. Because the Humpback Chub speciated in large erosive riverine habitats, its distribution in the upper basin is defined by the occurrence of canyon-confined areas within warm-water regions, and there is no evidence to suggest that the species was ever found equally abundant in intervening sand-bed reaches. The life history of the species and habitat use show that the Humpback Chub does not rely on sand-bed river reaches or floodplains, as do the other native species of the basin, including the Colorado Pikeminnow and Razorback Sucker.

Historical and contemporary distributional information, habitat associations, and genetic linkages provide a compelling case for the Humpback Chub historically occupying disjunct canyon areas with little movement of individuals among populations. Thus, connectivity among these populations is principally genetic at a decadal scale (Douglas and Douglas 2007), with little demographic exchange and interdependence. The disjunct distribution pattern and low level of exchange among populations have a significant bearing on resiliency, redundancy, and representation, as discussed in section 6.2 of this document.

2.4 Genetics and Hybridization

The Humpback Chub is a member of the *Gila* complex, a group of western cyprinid fishes that inhabit the rivers and streams of the arid southwestern United States. Species of the *Gila* complex show morphologic and genetic similarities, but display considerable phenotypic plasticity in different environments within and among species. Three species of the genus *Gila* inhabit the mainstem Colorado River and live sympatrically in some regions, including:

1. Humpback Chub (*Gila cypha*);
2. Bonytail (*Gila elegans*); and
3. Roundtail Chub (*Gila robusta*).

Four additional congeneric species and subspecies are isolates and primarily tributary inhabitants with little or no historical or present interaction with the Humpback Chub, including:

1. Virgin River Chub (*Gila robusta seminuda*);
2. Pahranagat Roundtail Chub (*Gila robusta jordani*);
3. Gila Chub (*Gila intermedia*); and
4. Headwater Chub (*Gila nigra*).

The Humpback Chub, Roundtail Chub, and Bonytail are historically sympatric mainstem species with substantial evidence of introgressive hybridization (Dowling and DeMarais 1993). This hybridization has resulted in high phenotypic plasticity with morphologic intergrades in all sympatric populations (Holden and Stalnaker 1970; Smith et al. 1979; McElroy and Douglas 1995; Douglas et al. 1998) that now occur only in the upper basin. Alleles characteristic of Bonytail and Roundtail Chub are present in the Grand Canyon (Douglas and Douglas 2007), where the three species no longer coexist, but were collected in the early 1940s (Bookstein et al. 1985).

In 2016, the American Fisheries Society and the American Society of Ichthyologists and Herpetologists Joint Committee on the Names of Fishes determined that the Gila Chub and the Headwater Chub are part of a single taxon—the Roundtail Chub—and the Service subsequently withdrew a proposal to separately list the Headwater Chub and the Roundtail Chub (Federal Register Vol. 82, No. 66, April 7, 2017, 16981). The Committee did not evaluate the taxonomic status of the other *Gila* species, and the Humpback Chub, Roundtail Chub, and Bonytail continue to be considered valid taxonomic species.

An examination of the genetic structure of the Humpback Chub and the Roundtail Chub in the Colorado River System shows that neither species could be discriminated using mitochondrial DNA (mtDNA), although markers successfully separated both species from the Bonytail (Douglas and Douglas 2007). The recent coalescence of lineages is most parsimoniously explained by an historical scenario in which both species were reduced to very small populations by an end-of-Pleistocene warming and drying event (~12,000 years ago) that forced them together into shrinking riverine habitat. They then hybridized, possibly backcrossing (progeny to parental forms) over an extended time. Eventually, pluvial conditions returned, the aquatic environment expanded, and the species returned to familiar and exclusive niches in their natal rivers. The large-scale population reduction would have reset their mtDNA evolutionary clocks, and hybridization would have provided both species with the same haplotype(s). This evolutionary history shows that the Humpback Chub has survived large historical environmental changes and periods of extensive hybridization.

As a result of the microsatellite (msat) analysis, Douglas and Douglas (2007) designated the following genetic subgroups of *Gila* for the Colorado River System:

1. *G. elegans*;
2. All Grand Canyon *G. cypha* aggregations;
3. Desolation Canyon *G. cypha* and *G. robusta;*
4. Upper basin *G. cypha* (excluding *G. cypha* from Desolation Canyon);
5. Upper basin *G. robusta* (excluding *G. robusta* from Desolation Canyon and Yampa River); and
6. Upper basin *G. robusta* from the Yampa River.

Although intergrades of Humpback Chub, Roundtail Chub, and Bonytail suggest extensive hybridization with possible concomitant loss of genetic diversity and evolutionary adaptive traits (Rosenfeld and Wilkinson 1989), some scientists believe that introgressive hybridization is part of the evolutionary history of the Colorado River *Gila* that has resulted in high adaptability to the variable and rigorous conditions of the Colorado River System (Dowling and DeMarais 1993). This hypothesis is supported by evidence of intergrades prior to extensive human alteration in the basin (Miller 1946). Hybridization and introgression among the three sympatric mainstem *Gila* species is evident in each of the five upper basin populations, but it is unclear if hybridization is enhanced by human alteration and if it reduces or replaces contemporary numbers of genetically distinct Humpback Chub.

In a more recent, but preliminary, genetic evaluation of upper basin Humpback Chub with comparisons to Roundtail Chub and Bonytail, Bohn (2016) and Bohn and Wilson (2017) determined that upper basin Humpback Chub are as genetically diverse as Roundtail Chub, and that there is no need to supplement upper basin Humpback Chub with lower basin genetic diversity. They recommend establishing Humpback Chub broodstocks for the lower basin and upper basin according to the following management units:

- Black Rocks and Westwater Canyon;
- Desolation, Gray, and Cataract Canyons; and
- Lower Basin.

Bohn and Wilson (2017) concluded that genetic clusters within Humpback Chub may reflect spawning site fidelity, and if so, spawning sites should be identified and preserved to prevent loss of diversity. They determined that the Black Rocks population contains the highest level of hybridization, but that present introgression is not likely related to anthropogenic activities. They caution that wild levels of introgression could increase in the absence of adequate spawning habitat, and advise that studies should be conducted to identify physical characters that best reflect underlying genetic structure of upper basin *Gila* spp.

2.5 Listing Status, Recovery Planning, and Consultations

The following is a chronology of listing actions for the Humpback Chub:

- First included in the List of Endangered Species issued by the Office of Endangered Species on March 11, 1967 (32 FR 4001);
- Considered as "endangered" under provisions of the Endangered Species Conservation Act of 1969 (16 U.S.C. 668aa);
- Received protection as "endangered" under Section 4(c)(3) of the Endangered Species Act of 1973, as amended (16 U.S.C. 1531 *et seq.*); and
- Included in the list of endangered and threatened species published in the Federal Register on January 4, 1974 (39 FR 1175).

The Humpback Chub is listed as "endangered" throughout its historical range in the states of Arizona, Colorado, Utah, and Wyoming in the List of Endangered and Threatened Wildlife and Plants (50 CFR 17.11 & 17.12); it is also listed in Mexico, although no specimens have been reported from that country (Miller 2005).

The following recovery plan and revisions have been developed for the Humpback Chub:

- Recovery Plan approved on August 22, 1979 (USFWS 1979);
- Revised Recovery Plan approved on September 19, 1990 (USFWS 1990); and
- Recovery Goals that amended and supplemented the 1990 revised plan were approved August 1, 2002 (USFWS 2002), but were withdrawn and declared of no force and effect by court order on January 18, 2006 (*Grand Canyon Trust et al., vs. Gale Norton et al.*, United States District Court for the District of Arizona, Order No. 04-CV-636-PHX-FJM).

Additional ESA-related actions for the Humpback Chub include:

- Critical habitat designated as six reaches totaling 610 kilometers (km) of the Colorado River System on March 21, 1994 (59 FR 13374), including 319 km in the upper basin and 291 km in the lower basin (Figure 5);
- There are no experimental (10[j]) populations for the species;
- There are no DPSs proposed or designated for the species, since it was listed prior to the 1996 Policy Regarding the Recognition of Distinct Vertebrate Population Segments (DPS; 61 FR 4721); and
- There are no Safe Harbor Agreements for the species, and the Lower Colorado River Multispecies Conservation Plan is a Habitat Conservation Plan that includes the Humpback Chub[1].

The Humpback Chub has been included in numerous Final Environmental Impact Statements (FEIS) and ESA Section 7 consultations throughout the Colorado River System, including:

- Numerous water projects in the upper basin as part of the Upper Colorado River Endangered Fish Recovery Program,[2] including the:
  - 15-Mile Reach Programmatic Biological Opinion (PBO; USFWS 1999);
  - Yampa River Basin PBO (USFWS 2005a);
  - Gunnison River Basin PBO (USFWS 2009a); and

[1] see: (http://www.lcrmscp.gov/fish/humpback_chub.html)
[2] see: (http://www.coloradoriverrecovery.org/documents-publications/section-7-consultation/consultation-list.html)

 - Operation of Flaming Gorge Dam FEIS, Biological Opinion and Record of Decision (Bureau of Reclamation 2006).

- Actions in the lower basin prior to and as part of the Glen Canyon Dam Adaptive Management Program,[3] including the:
  - 1978 Final Biological Opinion on the Operation of Glen Canyon Dam (USFWS 1978);
  - 1995 Biological Opinion and 1996 FEIS and Record of Decision on the Operation of Glen Canyon Dam (Bureau of Reclamation 1996);
  - FEIS for Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations of Lake Powell and Lake Mead, Record of Decision and Biological Opinion (U.S. Department of the Interior 2007);
  - 2008 Final Biological Opinion for the Operation of Glen Canyon Dam, with conservation measures that include Fall Steady Experimental Flows (2008–2012), High-Flow Experiments Protocol, and Nonnative Fish Control Protocol (USFWS 2008);
  - 2009 Supplemental Opinion for the Operation of Glen Canyon Dam (USFWS 2009b);
  - 2010 Biological Opinion for the Operation of Glen Canyon Dam (USFWS 2010);
  - 2016 Long-Term Experimental and Management Plan (LTEMP) EIS for Operation of Glen Canyon Dam (U.S. Department of the Interior 2016), and
  - 2016 Biological Opinion for the Glen Canyon Dam Long-Term Experimental and Management Plan, Coconino County, Arizona (USFWS 2016b).

- Actions of the Lower Colorado River Multi-Species Conservation Program[4], specifically:
  - 2005 Biological and Conference Opinion on the Lower Colorado River Multi-Species Conservation Program (USFWS 2005b).

[3] see: http://www.gcdamp.gov/
[4] see: http://www.lcrmscp.gov/general_program.html

3.0 SPECIES NEEDS

3.1 Factors That Control Life History Stages

The following is a description of resource needs for each of the seven life stages of the Humpback Chub, as depicted by a conceptual model (Figure 6). Abiotic and biotic factors that control or regulate the transition of individuals from one life stage to the next are enumerated and were used to help identify needs of the species at each life stage.

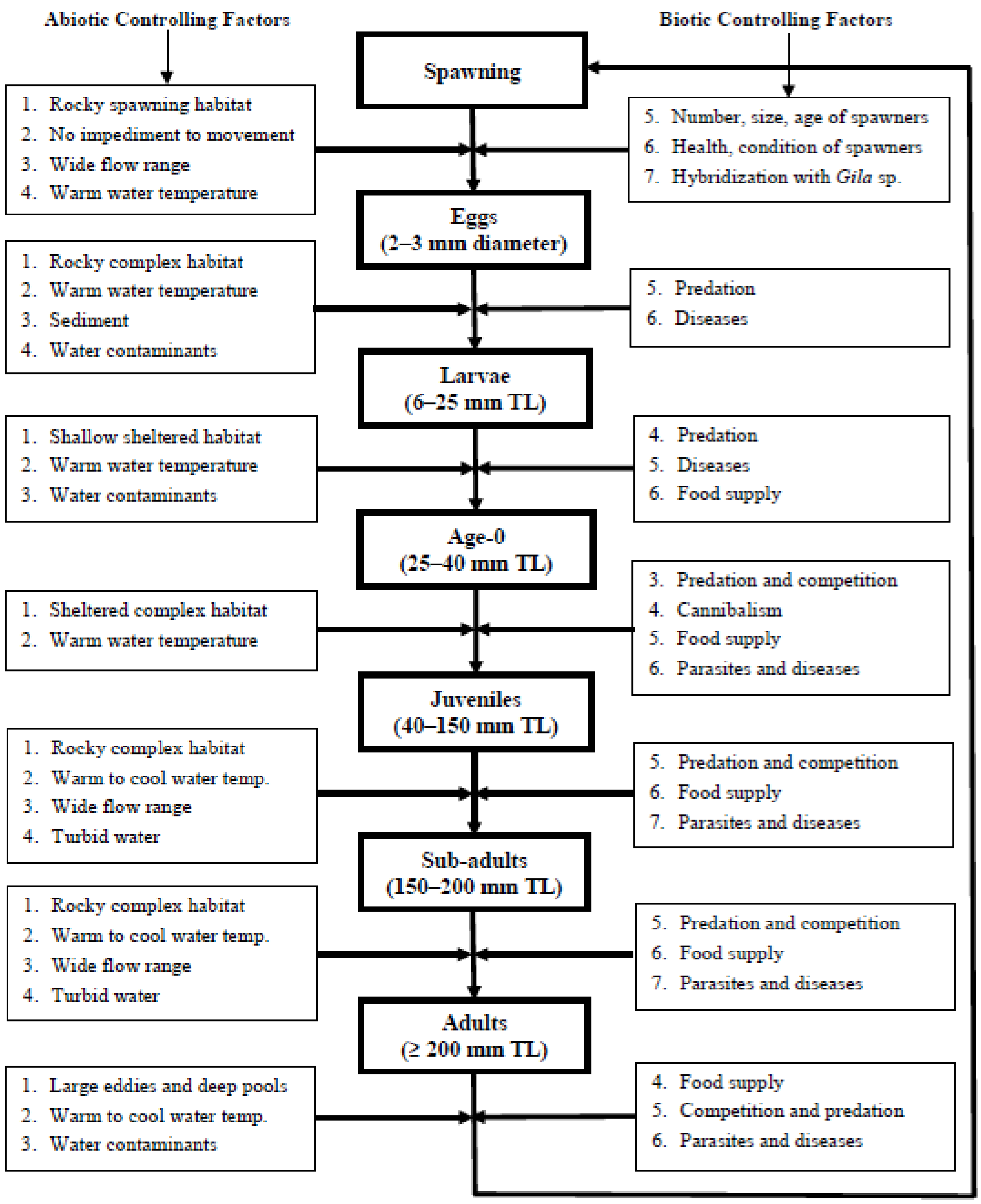

Figure 6. Life stages of the Humpback Chub with abiotic and biotic controlling factors.

3.1.1 Spawning—The Humpback Chub is a spring-time communal spawner that broadcasts and fertilizes its eggs on rocky substrates. Humpback Chub in the upper basin spawn in seasonally-warmed rivers and tributaries within population centers. In Grand Canyon, spawning likely occurred historically in the mainstem, but cold releases from Glen Canyon Dam starting in the late 1960s, have mostly precluded mainstem spawning, and the fish spawn primarily in the seasonally-warmed LCR. Spawning may have taken place historically in large tributaries, but reduced flows in the Paria River and Kanab Creek, and predators in Bright Angel Creek, Shinumo Creek, and Havasu Creek have rendered these tributaries largely inaccessible and unusable by the Humpback Chub.

The following identifies and describes the principal resource needs for spawning by factor:

1. **Rocky spawning habitat—**Spawning takes place in spring within the geographic boundaries of canyon-bound population centers usually along river margins and on mid-channel bars with boulder, cobble, and clean gravel substrate. In the upper basin, adults usually spawn in April–July, during or immediately after the peak of spring runoff and in the absence of detectable movement to specific locales (Valdez and Clemmer 1982; Kaeding et al. 1990); evidence of spawning in the Yampa River has been documented as late as September (Muth and Nesler 1993). In the Grand Canyon, adults spawn in March–April after moving short distances (< 15 km) from the cold Colorado River to the seasonally-warmed LCR (Valdez and Ryel 1995), where there is a subsequent ascent of up to 14 km (Douglas and Marsh 1996; Van Haverbeke et al. 2013). These spawning migrations to and from the LCR may be energetically costly and there is evidence of skipped-spawning, where some adults miss one or more years between spawning events (Yackulic et al. 2014; Pearson et al. 2015). There is also recent evident of mainstem spawning in western Grand Canyon (Rogowski et al. 2017).

2. **No impediment to movement—**There are no human-caused impediments to movement (e.g., waterfalls, dams, diversions) within or between the five upper basin populations. Fish passage has been installed on the Gunnison River and the upper Colorado River upstream of known populations that could allow the species to expand its distribution (see section 4.1.6). There is little movement of fish through the Grand Canyon (Paukert et al. 2006), although there is no impediment to movement in the mainstem (see section 4.2.6). An upstream barrier in the LCR is natural falls 14 km above the outflow, although passage by some marked fish is documented (Stone and Pillow 2015).

3-4. Wide flow range and warm water temperature—The Humpback Chub spawns at a wide range of flows and times in different populations, but at a rather narrow temperature range (Table 2). Suspected spawning in the upper basin has taken place from May 15 to September 6, and at a flow range of 65–60,000 cfs, but at a temperature range of only 15–24°C (Valdez and Clemmer 1982; Kaeding et al. 1990; Muth and Nesler 1993; Nelson et al. 2016). Although the species appears to spawn at a wide range of flow, inter-annual requirements are uncertain (e.g., flow change, spring peak).

Table 2. Dates, river flows, and water temperatures at which evidence of Humpback Chub spawning has been documented in the Colorado River System. Flow and temperature are from the nearest USGS gage for corresponding dates, unless otherwise indicated.

Population	Date	River Flow	Water Temperature	Reference
Black Rocks	June 2–15, 1980	21,500–26,000 cfs	18–20ºC	Valdez and Clemmer 1982
	May 15–25, 1981	3,000–5,000 cfs	17–19ºC	Valdez and Clemmer 1982
	June 20–July 30, 1983	14,000–60,000 cfs	15–20ºC	Kaeding et al. 1990
	June 25–July 31, 1984	10.500–42,000 cfs	17–22ºC	Kaeding et al. 1990
Cataract Canyon	June 15–23, 1988	41,500 cfs	20–23ºC	Valdez 1990
Yampa River (data for *Gila* spp. which included Humpback Chub)	June 17–August 24, 1980	5,600 cfs	18–20ºC	Muth and Nesler 1993
	June 6–August 22, 1981	2,400 cfs	16–24ºC	Muth and Nesler 1993
	June 17–September 5, 1982	6,000 cfs	15–21ºC	Muth and Nesler 1993
	June 18–September 6, 1983	7,000 cfs	No temperature data available	Muth and Nesler 1993
	June 12–August 23, 1984	9,700 cfs	No temperature data available	Muth and Nesler 1993
Little Colorado River	Commences mid-March to mid-April.	At high spring flows, spawning activity peaks as discharge approaches base flows (~230 cfs) in April	When mean water temperature rises above 14ºC, and preferably at 16–22ºC	Gorman and Stone 1999
	March and April 1981	No flow data available	18–20ºC	Kaeding and Zimmerman 1983
Colorado River in Grand Canyon (Fence Fault Spring, RM 30)	June 8, 1994; estimated from length of post-larvae.	12,000–19,000 cfs; mainstem flow.	16–19ºC; temperature in area of spring.	Valdez and Masslich 1999 Andersen et al. 2010
Colorado River in western Grand Canyon	April 29–July 24, 2015; estimated from fish length.	Mainstem flow range 9,000–18,000 cfs.	Mainstem temperature range 14–20ºC.	Kegerries et al. 2016
Havasu Creek	Unknown, age-0 fish captured in October.	Havasu base flows 65 cfs.	Timing of spawning unknown; ripe females and males found in May.	Nelson et al. 2016

In the Grand Canyon, spawning in the LCR takes place from mid-March to mid-April as discharge approaches base flow of 230 cfs and at a temperature of 16–22ºC (Kaeding and Zimmerman 1983; Gorman and Stone 1999). Evidence of spawning (i.e., post-larvae) was found in June in a riverside warm spring at 16–19ºC at mainstem flows of 12,000–19,000 cfs (Valdez and Masslich 1999; Andersen et al. 2010). Spawning has also been documented with translocated fish in Havasu Creek at an estimated flow of 65 cfs (Nelson et al. 2016). The occurrence of numerous young Humpback Chub in western Grand Canyon also indicates that mainstem spawning may be taking place in downstream reaches following warmer dam releases that started in 2004 (Rogowski et al. 2017). Lengths of larvae and age-0 fish indicate that spawning took place from April to July at a temperature of 14–20°C and a flow of 9,000–18,000 cfs (Kegerries et al. 2016).

5. **Number, size, and age of spawners—**The five upper basin populations are each comprised of relatively few numbers of individuals that range from ~300 to over 1,600 adults; few individuals remain in the DNM population. The lower basin population in the Grand Canyon is comprised of over 12,000 adults in the mainstem and two tributaries, with recent expansions in numbers and distributions of fish. Fish in the upper basin are smaller than those in the Grand Canyon, and the females presumably produce fewer young. The longevity of fish in the upper basin is ~20 years, whereas fish in the Grand Canyon appear to reach ~40 years of age. The number, size, and age of adult spawners is important to the reproductive potential of individual populations, and management objectives strive to increase the size and age composition of each population (see also section 6.2).

6. **Health and condition of spawners—**The health and condition of adult Humpback Chub is not specifically monitored, other than a record of lengths and weights of fish captured during monitoring and research activities. The length to weight relationships showed differences in condition of fish from each population from information collected during the 1980s and 1990s (Meretsky et al. 2000), but a comprehensive assessment was not repeated. The present condition of Humpback Chub in Grand Canyon may be lower than previously reported in 2000, possibly because increased numbers of fish may be limiting space and food (Dzul et al. 2017). The health and condition of individual fish have not been associated with decline of any single population.

7. **Hybridization with *Gila* species—**As described in section 2.3, the Humpback Chub can hybridize with Roundtail Chub or Bonytail where the species co-exist. Incidence of hybridization appears to be higher during periods of drought when spring flows are reduced in magnitude and less arduous conditions allow for invasions of Roundtail Chub (Kaeding et al 1990; Chart and Lentsch 1999; Francis and McAda 2011). Periodic high spring flows can reduce the numbers of Roundtail Chub—and nonnative predators—in population centers. Although introgressive hybridization may be part of the evolutionary history of the species, the effect of hybridization on contemporary populations is not understood.

3.1.2 Eggs—The Humpback Chub broadcasts 1–2 mm diameter eggs on rocky substrate; the fertilized eggs swell to 2–3 mm and become semi-adhesive as they lodge in the crevices and interstitial spaces of the substrate. The following identifies and describes the principal resource needs for egg deposition and incubation by factor:

1-2. Rocky complex habitat and warm water temperature—The Humpback Chub in the upper basin broadcasts its eggs over rocky substrate comprised of boulder, cobble, and gravel (Valdez and Clemmer 1982; Kaeding et al. 1990). Females each release ~2,500 eggs into the water column (Hamman 1982) where they are fertilized as they settle into interstitial spaces where water circulation keeps the semi-adhesive eggs aerated. The fertilized eggs are 2–3 mm in diameter (Snyder et al. 2016) and incubate for 4–11 days at 16–22ºC (Hamman 1982). In the Grand Canyon, Humpback Chub spawn primarily in the LCR, where eggs are deposited on complex angular substrates of boulders and clean gravel at depths of 0.5–2 m, at 16–22ºC, and during the descending limb of spring runoff (Gorman and Stone 1999). Evidence of spawning has also been found in a warm spring (source temperature 21.5°C) near the river's rocky edge in Marble Canyon (Valdez and Masslich 1999) and in the rocky channel of Havasu Creek (Nelson et al. 2016).

3-4. Sediment and water contaminants—The Humpback Chub evolved in the muddy and turbid Colorado River and the extent to which high sediment accumulation at low flow affects egg incubation and survival is unknown. The fish tend to spawn in relatively moderate to high channel velocity where sediment accumulation is not expected to affect incubation. Presumably, the short incubation time (generally ~5 days) precludes much sediment deposition over the incubating eggs.

The effect of contaminants on Humpback Chub eggs has not been evaluated, although selenium and mercury have been identified as having physiological effects on Razorback Sucker and Colorado Pikeminnow (Waddell and May 1995; Osmundson et al. 2000).

5-6. Predators and diseases—Nonnative fishes, such as Common Carp, Red Shiner, and Fathead Minnow, prey on eggs and young of native fishes (e.g., Rupert et al. 1993), as do native Speckled Dace. The effect of this predation at the population level is not known, but is not believed to be significant because incubating Humpback Chub eggs are typically deep in interstitial spaces of substrates at relatively high velocity and inaccessible to most fish. Diseases are known to affect eggs in hatcheries, but have not been assessed in the wild.

3.1.3 Larvae—Humpback Chub larvae hatch in interstitial spaces of rocky substrate. The following identifies and describes the principal resource needs for the larvae by factor:

1-2. Shallow sheltered habitat and warm water temperature—Newly-hatched Humpback Chub larvae are 6–7 mm long (Muth 1990) and emerge (swim-up) from the interstitial spaces ~3 days after hatching (Hamman 1982). Survival of swim-up larvae in a hatchery occurred at 12–22ºC, but was optimal at 16–22ºC (Hamman 1982). There is little evidence of long-distance larval drift in upper basin populations, but the larvae are carried passively by currents to nearby sheltered shorelines consisting of boulders, cobble, and gravel (Valdez 1990). The five known populations in the upper basin are restricted to relatively small areas of river, and larvae have rarely been found downstream of these population centers (Valdez and Williams 1993).

The majority of larvae in the Grand Canyon are produced and remain in the lower 14 km of the LCR. Some larvae drift downstream from the LCR (Childs et al. 1998; Robinson et al. 1998) into the colder mainstem and likely die of thermal shock when mainstem temperatures are cold (Clarkson and Childs 2000). Transition checks on scales of age-0 fish indicate little or no survival of fish < 52 mm TL that drift from ~20°C in the LCR to ~10°C in the mainstem (Valdez and Ryel 1995). Hence, fish that egress from the LCR as larvae have lower survival than fish that leave at a larger size during or after the summer monsoon floods (Limburg et al. 2013). Warmer dam releases starting in 2004 have resulted in higher survival of young transitioning from the LCR to the mainstem (Dodrill et al. 2014).

Larvae and age-0 fish have been found in and downstream of warm springs in Marble Canyon (RM 30–61; Valdez and Masslich 1999; Andersen et al. 2010), and have also been found in the mainstem in western Grand Canyon. In May–September 2014 and 2015, 18 and 67 larval Humpback Chub, respectively, were caught in the mainstem Colorado River downstream of Lava Falls (RM 188–254) (Kegerries et al. 2016). Many of these fish were in the mesolarval and metalarval phases (8–12 days old), indicating that they originated from proximate locales and not the LCR, which is over 200 km upstream. The natal origin of these fish is unknown, but their young age and a lack of documented long-distance drift by the species is evidence that successful reproduction is taking place in the mainstem or tributaries of western Grand Canyon (Healy et al. 2014a; Nelson et al. 2016; Rogowski et al. 2017).

3. Water contaminants—There is a large suite of water contaminants in the Colorado River that may affect fish in various ways. Larval fish are susceptible to effects of contaminants because of contaminant accumulation through food organisms or waterborne exposure. Waddell and May (1995) determined that concentrations of selenium were highest in Razorback Sucker close to point sources associated with floodplains and drains; these areas are not in proximity of Humpback Chub populations and the effect of selenium is expected to be less. The effect of contaminants on Humpback Chub has not been investigated.

4-5. Predators and diseases—Larval Humpback Chub are small and vulnerable to predation by various fish species, including Common Carp, Red Shiner, Fathead

Minnow, and Speckled Dace. This type of predation exists, but the effect at the population level is not known. Notably, larval and post-larval Humpback Chub use very shallow habitat where photosynthetic production of food is high and access by larger predators is limited. Diseases of larval Humpback Chub in the wild have not been investigated.

6. **Food supply—**The early protolarval phase relies on a yolk sac for nutrition, but the yolk sac is completely absorbed and the mouth becomes functional in the late mesolarval phase at ~11 mm TL. Fin rays begin to develop in the post-flexion mesolarval phase and are fully developed in the metalarval phase before the fish transition to age-0 (Figure 7). Larvae and age-0 fish feed on diatoms, algae, and small invertebrates (e.g., rotifers, cladocerans, and copepods) present in shallow-water periphtyon communities.

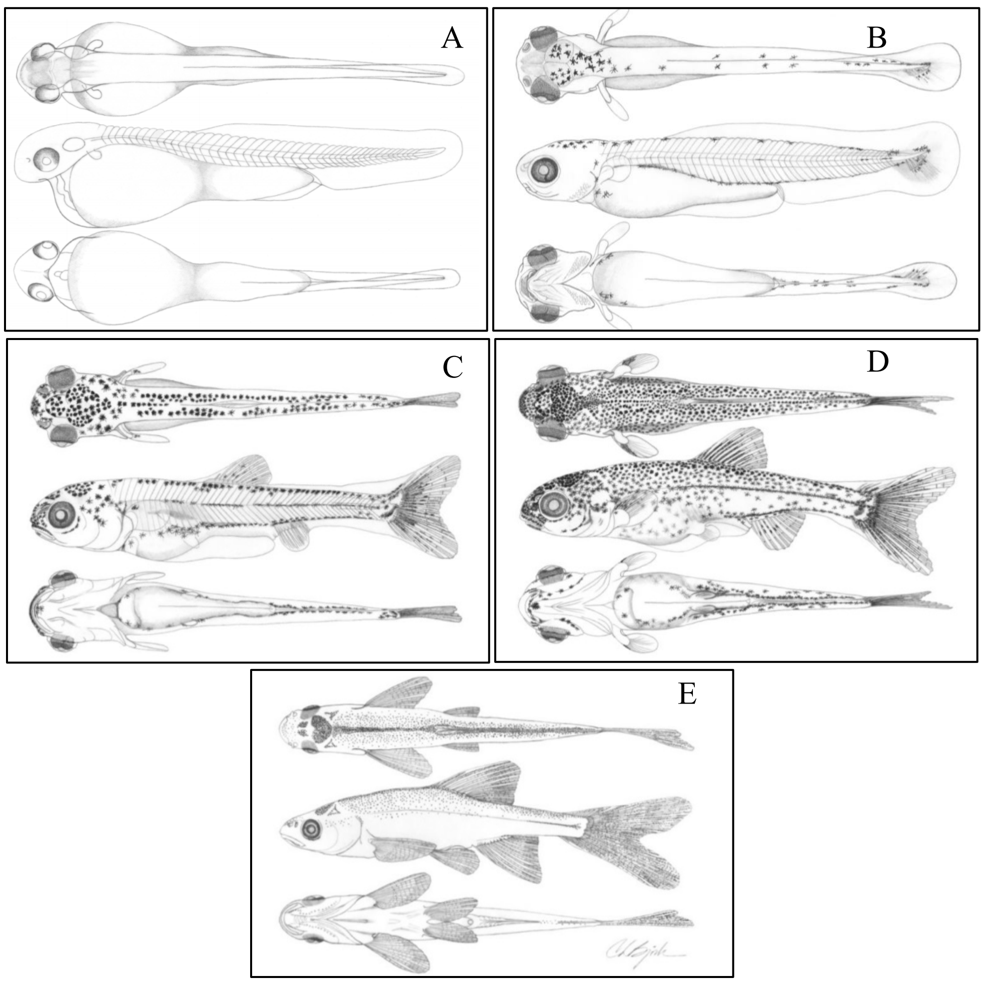

Figure 7. Illustrations of larval phases of Humpback Chub as (A) protolarva with yolk, (B) mesolarva with yolk, (C) postflexion mesolarva near transition to metalarva, (D) metalarva, and (E) juvenile life stages. Illustrations by C. Lynn Bjork from Snyder et al. (2016).

3.1.4 Age-0—Humpback Chub transform from the larval stage to age-0 at ~25 mm TL or 30–40 days of age, at which time they have fully developed fins and a functional mouth (Hamman 1982; Muth 1990). The following identifies and describes the principal resource needs for the age-0 fish by factor:

1-2. Sheltered complex habitat with warm water temperature—Age-0 Humpback Chub use rocky complex shorelines of boulders, talus, cobble, and vegetation where they hide in interstitial spaces during the day and emerge to feed under reduce light (Converse et al. 1998; Korman et al. 2004). Age-0 fish may also be found in sandy backwaters of the Grand Canyon, although this feature comprises a small portion of available habitat in canyon reaches (Ackerman 2008; Dodrill et al. 2014).

Age-0 Humpback Chub display measureable growth at a temperature of 12–24ºC, but optimal temperature for growth is 16–22ºC (Gorman and VanHoosen 2000). In the Grand Canyon, some age-0 fish remain and mature in the LCR, but most move, or are transported into the mainstem by monsoonal rainstorm floods at 3–4 months of age (Valdez and Ryel 1995). Most young fish in the Grand Canyon remain in the mainstem until maturity and subsequently return to the LCR for spawning (Douglas and Marsh 1996; Yackulic et al. 2014).

Otolith microchemistry of Humpback Chub from the LCR suggests a size advantage for fish that remain in the LCR for longer time periods in their first year of life; this size advantage may persist when the fish egress into the mainstem Colorado River (Limburg et al. 2013). Fish that egress from the LCR prior to the monsoon season have lower survival than fish that egress at a larger size during or after the high summer monsoon flows. For Humpback Chub, survival is thought to be strongly influenced by age and size, as acknowledged in a stock assessment framework developed for the species (Coggins et al. 2006).

Little is known about age-0 Humpback Chub in the upper basin, as these fish are difficult to sample and distinguish morphologically from the sympatric Roundtail Chub.

3-4. Predation and competition—Young Humpback Chub are susceptible to predation from sympatric piscivores because they lack spines and sharp scales. They may also be naïve to predators because of their evolutionary history in a river system with low fish diversity and small numbers of predatory fish. In the Grand Canyon, young Humpback Chub are particularly susceptible to predation by introduced Rainbow Trout and Brown Trout because of reduced swimming ability in the cold clear waters of the mainstem Colorado River (Valdez and Ryel 1995; Yard et al. 2011). Channel Catfish and Black Bullhead are predators in the LCR (Marsh and Douglas 1997), where adult and juvenile Humpback Chub are also cannibalistic under high densities of young (Gorman and Stone 1999). In upper basin populations, young Humpback Chub are particularly susceptible to predation from introduced Channel Catfish and Smallmouth Bass because of densities of these large predatory fish in humpback chub habitats. Smallmouth Bass densities in Humpback Chub habitats are influenced by upstream areas of production; sympatric reproduction is uncommon, thus reducing densities in humpback chub habitats compared to other upper basin reaches.

5. **Food supply—**The diet of age-0 Humpback Chub is primarily diatoms, algae, and small invertebrates (e.g., rotifers, cladocerans, copepods) (Minckley 1997). The availability of these small food items at the proper time of year is essential for growth and survival of the young fish.

6. **Parasites and diseases**—A suite of parasites is known from Humpback Chub that may affect condition and survival of individuals (Flagg 1982; Hoffnagle et al. 2006), but no known outbreak has occurred that has dramatically affected an entire population. The Asian tapeworm (*Bothriocephalus acheilognathi*) and the parasitic copepod (*Lernaea cyprinacea*) are common warm-water parasites of the Humpback Chub that can lead to stress, risk of infection or secondary disease, and possibly death of individual fish. In the Grand Canyon, the Asian tapeworm is most likely contracted by fish in the LCR where they consume a warm-water cyclopoid copepod that is host to the early life stage of the parasite (Valdez and Ryel 1995). Similarly, the parasitic copepod, *Lernaea*, is most likely contracted in warm quiet waters that contain the free-swimming early stages of the parasite. Since both parasites need ~20°C temperature to mature and reproduce, infections generally occur in warm river reaches and tributaries.

3.1.5 Juveniles—Age-0 Humpback Chub transition into the juvenile stage at 1 year of life, or at ~40 mm TL, and they become sub-adults or recruits at ~150 mm TL. The following identifies and describes the principal resource needs for juveniles by factor:

1. **Rocky complex habitat—**Juveniles in the upper basin use rocky complex habitat, often along shorelines, and they move to increasingly deeper offshore areas of large boulders and cobble with increasing size and age (Karp and Tyus 1990; Valdez et al. 1990; Chart and Lentsch 1999). Juveniles in the Colorado River in Grand Canyon use rocky talus shorelines where they move up-slope and down-slope to maintain position with depth and velocity under changing water levels from dam operations (Converse et al. 1998; Trammell et al. 2002; Korman et al. 2004). Juveniles in the mainstem may also use backwaters, but this habitat feature is rare, ephemeral, and usually contains a small portion of the overall number of juveniles in the system (Dodrill et al. 2014). Habitat of juveniles in the LCR is deep mid-channel pools and chutes with large boulders and cobble (Stone and Gorman 2006).

2. **Warm to cool water temperature—**Temperature is an important factor in the growth and survival of juvenile Humpback Chub. Juveniles grow and survive well at 17–27ºC (Bulkley et al. 1982), which is within the range of summer temperatures in the upper basin and the seasonally-warmed LCR. Temperature in the mainstem Colorado River

through Grand Canyon is usually colder, which results in slower growth than in the LCR (Robinson and Childs 2001). Generally, water temperature of ~12–27ºC is suitable for growth, with an optimal range of 16–22ºC (Gorman and VanHoosen 2000).

Although the Humpback Chub is a warm-adapted species, there appear to be benefits to later life stages from cooler temperature. Growth in the cooler Colorado River in Grand Canyon is slower than in the LCR, but individuals in the mainstem live longer (Yackulic et al. 2014), have better body condition (Meretsky et al. 2000), and carry fewer parasites (Hoffnagle et al. 2006). Cooler mainstem temperature limits development and reproduction of the Asian tapeworm and the parasitic copepod, *Lernaea*, which are common warm-water parasites of the Humpback Chub (Hoffnagle et al. 2006).

3. **Wide flow range—**Juvenile Humpback Chub have a demonstrated ability to live in a wide range of flows. In places like Cataract Canyon, the species has persisted despite experiencing annual flow range of 3,000 to 100,000 cfs (Valdez 1990). In the Grand Canyon, juveniles have a demonstrated ability to remain at suitable depth and velocity by adjusting position along rocky talus shorelines during dam releases of 5,000 to 25,000 cfs (Converse et al. 1998; Korman et al. 2004). During September and October of 2008–2012, dam releases were kept relatively steady within a range of 8,000–15,500 cfs; juvenile survival of 37–67% was not significantly different for approximately steady vs fluctuating flows (Finch 2012). Growth and survival of juveniles were higher but not significant under fluctuating flows, and relatively steady flow did not improve either. These studies suggest that growth and survival of juvenile Humpback Chub are robust to a wide range of contemporary flows.

4. **Turbid water—**Juvenile Humpback Chub are most active during mornings and evenings under low light conditions, and during flooding when turbidity is high (Valdez and Ryel 1995); the fish evidently use turbidity for safe movement and cover from predators. Given that the Colorado River is historically turbid, increased activity in turbidity is an apparent evolutionary adaptation for cover from predators (Ward and Morton-Starner 2015) and for increased food availability delivered by floods (Valdez and Hoffnagle 1999).

5. **Predation and competition—**As with age-0 fish, juvenile Humpback Chub are susceptible to predation because they lack spines and sharp scales and may be naïve to predators. In the Grand Canyon, juvenile Humpback Chub are susceptible to predation and competition by Rainbow Trout and Brown Trout (Valdez and Ryel 1995; Yard et al. 2011). The species is also highly susceptible to predation in the confined environment of the LCR (Marsh and Douglas 1997), where a school of large predators, such as Channel Catfish or Striped Bass, could move into the tributary and consume a large number of Humpback Chub. In upper basin populations, juvenile Humpback Chub are susceptible to predation from introduced Channel Catfish and Smallmouth Bass. Smallmouth Bass

densities in Humpback Chub habitats are influenced by upstream areas of production; Humpback Chub habitats do not support large densities of reproducing Smallmouth Bass.

6. **Food supply—**Juvenile Humpback Chub consume a variety of foods, including aquatic insects (e.g., black flies and midges) and crustaceans, as well as terrestrial insects when available (e.g., grasshoppers, Mormon crickets) (Jacobi and Jacobi 1982; Tyus and Minckley 1988; Valdez and Ryel 1995). These food resources resemble historic conditions in the upper basin, but have been altered in composition and abundance by cold and varying dam releases in the Grand Canyon.

7. **Parasites and diseases**—Juvenile Humpback Chub that carry the Asian tapeworm or the parasitic copepod, *Lernaea*, probably contracted these warm-water parasites in the LCR or another warm tributary or area in the Grand Canyon. Although water temperature in the mainstem is generally < 20°C, these parasites survive but cannot reproduce, unless the fish accesses a warm area, such as the LCR.

3.1.6 Sub-adults—Resource needs are not described specifically for sub-adults because of their overlap with those of juveniles and adults. Nevertheless, sub-adults are distinguished from juveniles in this assessment because they constitute the fish that are recruits, or those individuals that will mature to reproductive adults in the next 1–2 years of life, and because their needs differ somewhat between basins. In the upper basin, there is little difference between juveniles and sub-adults, except for a transition in habitat to deeper water with size and age. Juveniles reach the sub-adult stage at ~150 mm TL, or 2–3 years of age.

The timing and age for Humpback Chub development are largely temperature dependent, with fish in warm habitats reaching maturity in 3–4 years, whereas fish in the colder Colorado River in Grand Canyon may require 8–15 years to reach maturity (Coggins and Pine 2010; Yackulic et al. 2014). In the lower basin, the transition to sub-adults and adults is confounded by differences in water temperature between the seasonally-warmed LCR and the colder mainstem (Coggins and Pine 2010). Life-long residents of the LCR grow quickly to adulthood and have shorter life expectancies; whereas, fish that hatch in the LCR and transition to the mainstem as juveniles, grow much slower and require longer to become sub-adults. Sub-adults that rear in the mainstem take more than twice as long to reach adulthood and are ~40% less likely to survive to adulthood; however, these fish live much longer, on average, than adults reared in the LCR (Yackulic et al. 2014).

3.1.7 Adults—Adult Humpback Chub use deep pools and large eddies and they consume a variety of foods. The following identifies and describes the principal resource needs for adults by factor:

1. **Large eddies and deep pools—**Adults in the upper basin use primarily offshore habitats, including large eddies and deep pools, but they move to feed in shallow complex

shoreline habitats at night or during periods of high turbidity (Valdez 1990; Chart and Lentsch 1999). Adults in the Grand Canyon use primarily large recirculating eddies and deep pools where they feed on entrained foods carried by the river, but they also feed along shorelines at night and at times of moderate to high turbidity (Valdez and Ryel 1995). Adults may move daily within large recirculating eddy complexes (Gerig et al. 2014). Adults in the LCR and those translocated to other tributaries (Shinumo and Havasu creeks) also use the deepest pools available (Healy et al. 2014a; Nelson et al. 2016).

2. **Warm to cool water temperature—**The Humpback Chub is a warm-water species, and age and size at maturity are largely temperature-dependent, but may also vary with population. Male Humpback Chub in the upper basin and in the seasonally-warmed LCR generally mature at 3–4 years of age, and females generally mature at 4–5 years of age (Hamman 1982; Valdez and Ryel 1995). Fish that inhabit the colder mainstem in Grand Canyon may take 8–15 years to mature (Yackulic et al. 2014).

   Like juveniles and sub-adults, the adults in the colder mainstem in Grand Canyon are in generally better condition (Meretsky et al. 2000), have fewer parasites (Hoffnagle et al. 2006), and live longer (Yackulic et al. 2014) than adults in the seasonally-warmed LCR. Measureable growth of adults occurs at 12–27ºC, but is optimal at 16–22ºC. The species is able to live year-round in cooler water of 12–18ºC with slower growth but greater longevity and higher survival, as seen in the Colorado River in Grand Canyon.

   The longevity of the Humpback Chub also appears to be temperature-dependent. Adults that spend most of their time in the colder mainstem in the Grand Canyon appear to live up to 40 years, based on tag recaptures and growth rates (Coggins et al. 2006); whereas fish that spend most of their time in the seasonally-warmed LCR and fish in the upper basin live ~20 years. An examination of captured and recaptured Humpback Chub in the upper basin from the STReaMS database revealed a maximum of 16 years between initial capture of a fish 246 mm TL in 1994, and 392 mm TL at last capture in 2010. This fish was likely 4–6 of age at initial capture (based on length-age relationship) and was therefore 20–22 years of age at recapture (STReaMS, July, 2016).

3. **Water contaminants—**The Colorado River contains a large suite of municipal, agricultural, and industrial pollutants (including mining wastes and airborne chemicals) that potentially directly or indirectly affect many aspects of the species' life history. Loss of Humpback Chub to stochastic events, such as oil spills, large ash flows, and debris flows, are documented, but the possible insidious effects of low-levels of various elements or chemicals, such as mercury, selenium, or various petroleum compounds, have not been investigated and are largely unknown.

4. **Food supply—**Adult Humpback Chub feed actively on floating material entrained in eddies and low-velocity areas during floods and high fluctuating flows. The fish feed on

aquatic insects, crustaceans, plants, seeds, and occasionally small fish, as well as terrestrial insects and reptiles (Valdez and Ryel 1995). High flows are often food-laden and turbid and individuals appear to use turbidity as cover from predators and competitors. The fish feed extensively on sporadic food supplies brought on by large flow events, as observed during an artificial flood in the Grand Canyon (Valdez and Hoffnagle 1999), and with seasonal phenomena such as grasshopper infestations or Mormon cricket emergences and migrations (Tyus and Minckley 1988). In Grand Canyon, the availability and timing of food in the LCR may dictate when fish move to the mainstem; i.e., food availability in the LCR is highest in April and May, but lower in summer, fall, and winter, limiting carrying capacity and likely forcing or facilitating fish to move to the mainstem with monsoonal floods.

5. **Competition and predation**—Adult Humpback Chub are usually too large for most predators that inhabit the Colorado River to consume, except for an occasional large Channel Catfish, Northern Pike, or Striped Bass (the latter two of which are rare in Humpback Chub habitats). Competition for food and space, however, is possible with a number of species, especially introduced nonnative fishes, such as Smallmouth Bass, Walleye, Largemouth Bass, and Green Sunfish in the warm-water regions of the upper basin. However, densities of these species are either low, or variable to environmental conditions, demonstrating habitats occupied by Humpback Chub are not conducive to establishment of large populations of these nonnative fish. Spurgeon et al. (2014) determined that Humpback Chub and introduced Rainbow Trout in the Grand Canyon use similar food resources high in the food web, suggesting that the two species occupy a similar energetic niche following the changes brought about by Glen Canyon Dam. Competition from native Roundtail Chub is also possible where the species are sympatric in upper basin populations.

6. **Parasites and diseases**—Like juvenile Humpback Chub, adults that carry the Asian tapeworm or the parasitic copepod, *Lernaea*, probably contracted these warm-water parasites in the LCR or another warm tributary or area in the Grand Canyon. Although water temperature in the mainstem is generally < 20°C, these parasites survive but cannot reproduce, unless the fish access a warm area, such as the LCR.

3.2 Species Needs Categories

The needs of the Humpback Chub are drawn from the life history description in section 3.1. A summary of life stages, species needs, and information sources (i.e., references) is provided in Table 3. These species needs are grouped into the following eight categories as necessary aspects of the environment of the species (Figure 8). These species needs categories become the basis for describing current and future condition for the Humpback Chub in this status assessment. Photographs of habitats that illustrate some of these resources are shown in Figures 9–10.

1. Diverse rocky canyon river habitat
   a. Spawning: rocky substrate of boulder, cobble, and clean gravel, usually along river margins and on mid-channel bars.
   b. Eggs: complex habitats with rocky substrate of boulder, cobble, and gravel with clean interstitial spaces.
   c. Larvae: shallow sheltered habitat with boulders, cobble, and gravel with clean interstitial spaces.
   d. Age-0: shallow shorelines of boulders, cobble, talus, and vegetation.
   e. Juveniles and sub-adults: deep sheltered shorelines of boulders, cobble, talus, and vegetation.
   f. Adults: deep shorelines and offshore habitats, including large recirculating eddies and pools.
2. Suitable river flow and temperature
   a. Spawning: water temperature of 16–22ºC; wide flow range near spring runoff.
   b. Eggs: water temperature of 16–22ºC; optimal 21–22ºC; wide flow range.
   c. Larvae: water temperature of 12–22ºC; optimal 16–22ºC; susceptible to cold shock; wide flow range.
   d. Age-0: water temperature for growth, 12–24ºC; optimal 16–22ºC.
   e. Juveniles and Sub-adults: water temperature for growth, 12–27ºC; optimal 16–22ºC.
   f. Adults: water temperature for growth, 12–27ºC, optimal 16–22ºC; cooler water of 12–18ºC results in slower growth but greater longevity.
3. Adequate and reliable food supply
   a. Larvae: begin feeding at mesolarval and metalarval phases on diatoms, algae, and small invertebrates (e.g., rotifers, cladocerans, and copepods).
   b. Age-0: small food items such diatoms, algae, and small invertebrates (e.g., rotifers, cladocerans, copepods), and aquatic insects (midges and blackflies).
   c. Juveniles, sub-adults, and adults: a variety of foods, including aquatic insects (midges and blackflies), crustaceans, plants, seeds, and terrestrial insects and reptiles delivered by flood events; adults eat fish and may cannibalize young.
4. Habitat with few nonnative predators and competitors
   a. A fish community with few or no nonnative predators or competitors that is compatible with a viable reproducing population of Humpback Chub.
   b. Rocky or vegetated cover and water turbidity for safe movement and cover from predators during feeding.
5. Suitable water quality
   a. Water free of contaminants, or with low levels that do not produce detrimental effects to individuals.

   b. Security from spills of petroleum products and other toxic materials.

6. Unimpeded range and connectivity
   a. Free movement of fish with no impediments to access habitats necessary for all life stages.
   b. Suitable habitat and a full range of conditions necessary for life stages.
7. Persistent populations
   a. Sufficient numbers of independent reproducing groups of fish to ensure redundancy and resiliency.
   b. Adequate numbers of individuals in each population to ensure reproductive potential, recruitment, and long-term persistence.
8. High genetic diversity
   a. High genetic diversity within and across populations to ensure adaptive traits.
   b. Minimization of introgressive hybridization with other *Gila* species.

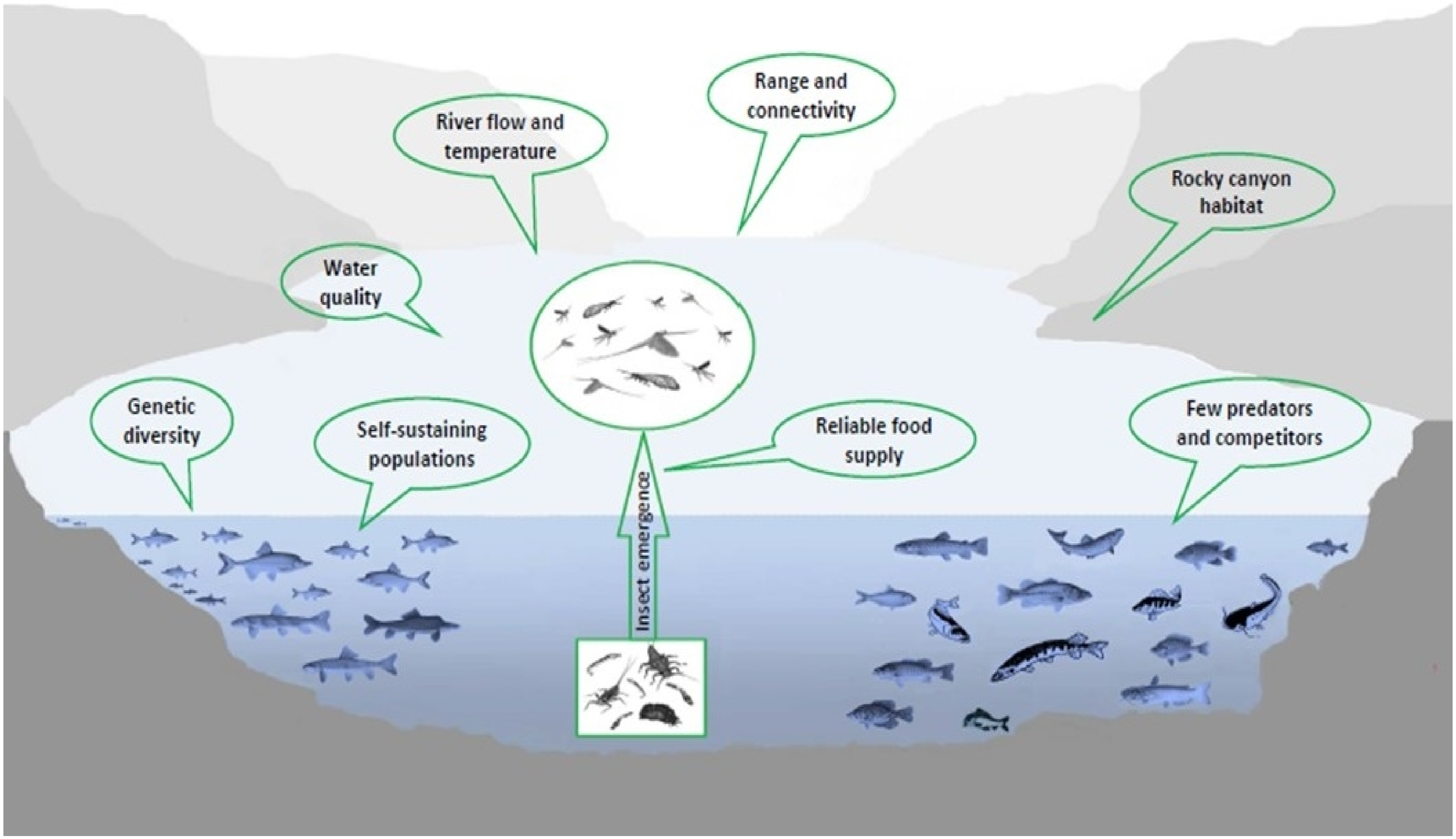

Figure 8. Species needs categories for the Humpback Chub.

Table 3. Summary of species needs for the Humpback Chub by life stage and references for information.

Life Stage	Species Need	Reference
Spawning	• Rocky substrates of boulder, cobble, talus and gravel, usually along river margins and on mid-channel bars, 0.5–2.0 m deep. • Water temperatures of 16–22ºC; wide flow range of 65–60,000 cfs.	• Kaeding et al. 1990 • Valdez and Clemmer 1982 • Gorman and Stone 1999
Eggs (1–2 mm diameter when deposited; 2–3 mm when fertilized)	• Complex habitats with rocky substrates of boulder, cobble, and clean gravel • Semi-adhesive eggs are deposited at depths of 0.5–2 m. • Water temperature of 16–22ºC, optimal 21–22ºC. • Habitat with few nonnative predators and competitors that may limit egg survival.	• Hamman 1982 • Valdez and Clemmer 1982 • Kaeding et al. 1990 • Gorman and Stone 1999
Larvae (6–25 mm TL)	• Clean, silt-free gravel for shelter after hatching . • Shallow shorelines with boulders, cobble, and gravel. • Warm currents for short-range drift, 12–22ºC, optimal 16–22ºC; susceptible to cold shock. • At mesolarval and metalarval phases, feed on diatoms, algae, and small invertebrates. • Habitat with few nonnative predators and competitors that may limit larval survival.	• Muth 1990 • Valdez 1990 • Childs et al. 1998 • Clarkson and Childs 2000
Age-0 (25–40 mm TL)	• Shallow shorelines of boulders, cobble, talus, backwaters, or vegetation. • Warm waters for growth, 12–24ºC, optimal 16–22ºC. • Small food items such diatoms, algae, and small invertebrates (e.g., rotifers, copepods). • Habitat with few nonnative predators and competitors that that may limit age-0 survival.	• Converse et al. 1998 • Gorman and VanHoosen 2000 • Korman et al. 2004 • Dodrill et al. 2014
Juveniles (40–150 mm TL)	• Complex shoreline habitats with large boulders and cobble. • Turbid water for safe movement and cover from predators during feeding. • Warm waters for growth, 12–27ºC, optimal 16–22ºC. • A variety of foods, including aquatic insects (black flies and midges) and crustaceans. • Habitat with few nonnative predators and competitors that may limit juvenile survival.	• Converse et al. 1998 • Bulkley et al. 1982 • Gorman and VanHoosen 2000 • Kennedy et al. 2013 • Dodrill et al. 2014
Sub-adults (150–200 mm TL)	• Complex shoreline habitats, with larger fish using increasingly deeper offshore habitats with large boulders and cobble. • Turbid water for safe movement and cover from predators during feeding. • Warm waters for growth, 12–27ºC, optimal 16–22ºC. • A variety of foods, including aquatic insects (black flies and midges) and crustaceans. • Habitat with few nonnative predators and competitors that may limit sub-adult survival.	• Bulkley et al. 1982 • Valdez and Ryel 1995 • Gorman and VanHoosen 2000 Kennedy et al. 2013 • Dodrill et al. 2014 • Yard et al. 2011
Adults (≥ 200 mm TL)	• Offshore habitats of greater depth, including large eddies, deep pools. • Turbid water for safe movement and cover from predators during feeding. • Warm waters for growth, 12–27ºC, optimal 16–22ºC, cooler waters for longer survival, 10–18ºC. • A variety of foods, including aquatic insects, crustaceans, plants, seeds, and occasionally small fish; as well as terrestrial insects and reptiles delivered by flood events. • Habitat with few nonnative predators and competitors that may limit adult survival. • Periodic high spring flows to reduce incidence of hybridization with sympatric *Gila.*	• Hamman 1982 • Valdez and Ryel 1995 • Kennedy et al. 2013 • Dzul et al. 2017 • Yackulic et al. 2014 • Dodrill et al. 2014 • Chart and Lentsch 1999

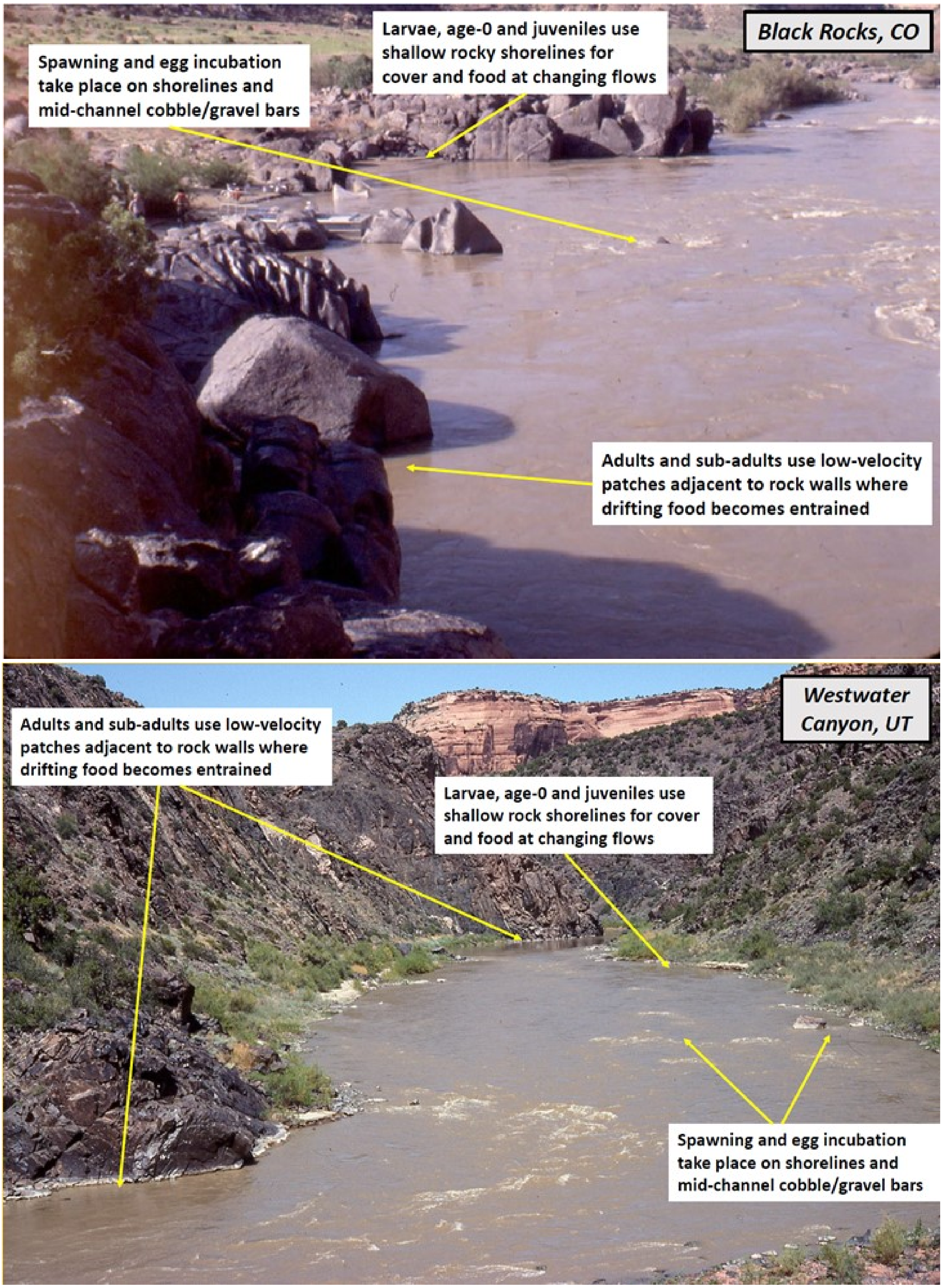

Figure 9. Life history needs of the Humpback Chub in Black Rocks, CO (top), and Westwater Canyon, UT (bottom), of the upper Colorado River basin.

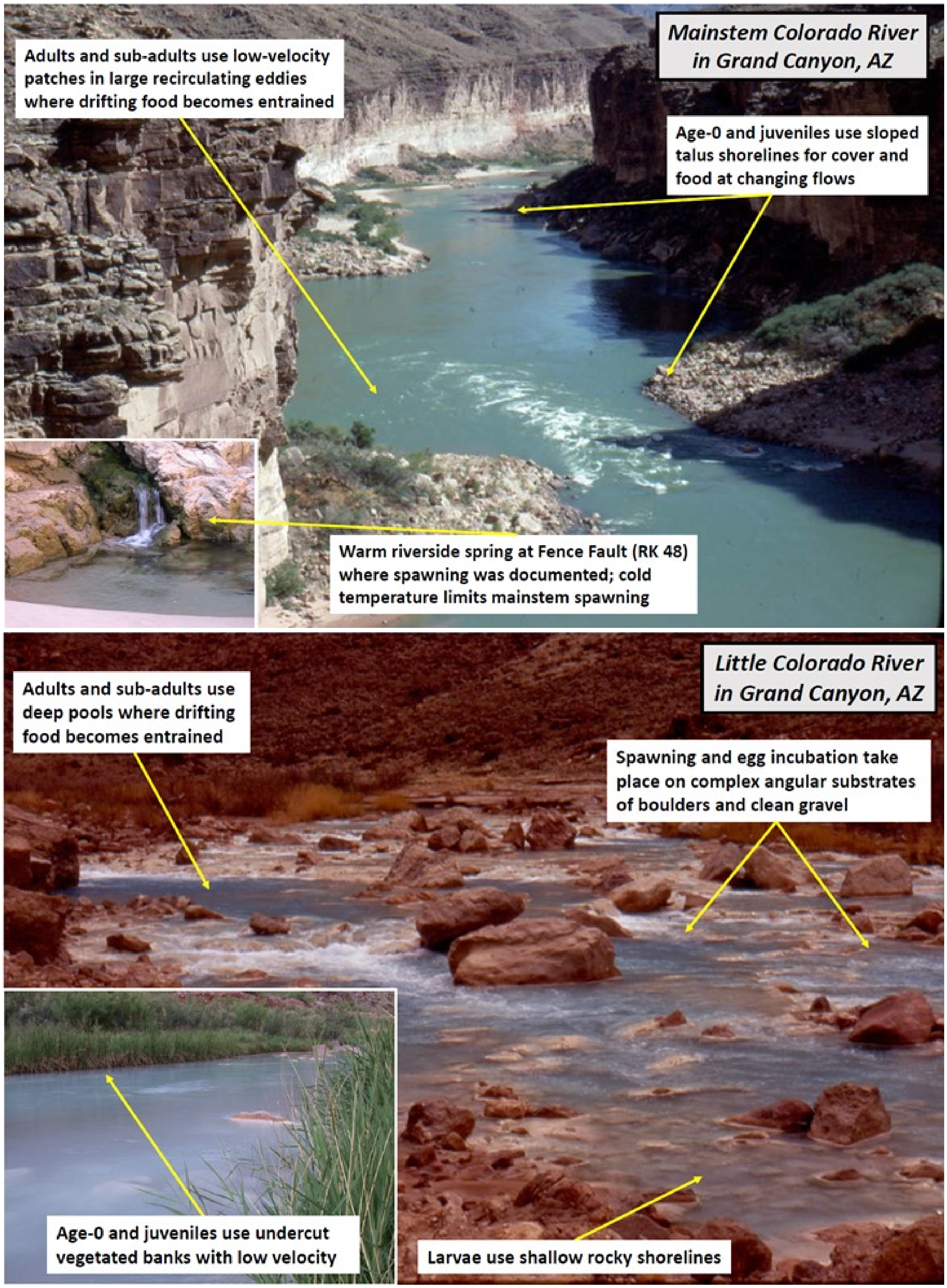

Figure 10. Life history needs of the Humpback Chub in the mainstem Colorado River (top) and the Little Colorado River (bottom) in Grand Canyon, AZ.

4.0 CURRENT CONDITION

This section describes the current condition of the Humpback Chub's habitat and demographics, and the probable explanations for past and ongoing changes in abundance and distribution within the species' ecological settings. First, current conditions of the species' resource needs are described by species needs category (as outlined in section 3.2). Sections 4.1 and 4.2 provide detailed descriptions of the current condition of these categories in the upper basin and lower basin, respectively. Section 4.3 then provides a summary of the current condition of these categories in each of the six Humpback Chub populations. Section 4.4 describes the ongoing conservation and management actions that influence the current condition of specific resources needs. Finally, section 4.5 describes the most up-to-date population monitoring data for the six populations, demonstrating population size and trajectory.

4.1 Upper Basin Current Resource Conditions

4.1.1 Diverse Rocky Canyon River Habitat—The following is a summary of rocky canyon habitat in populations of the upper basin followed by a detailed description:

- Rocky canyon habitat is largely unchanged and located in lands administered by federal, state, and tribal agencies that protect the current condition;
- The only major change to historical canyon habitat is inundation by reservoirs formed by large mainstem dams in the 1960s;
- Altered flow regimes have modified sediment budgets and allowed shorelines to be invaded by nonnative vegetation, but with minimal effect to canyon areas; and
- Riverine habitat is expanding in Cataract Canyon, as Lake Powell has receded since 2002 and the river continues to erode lake sediment and expose the historical river channel.

The Humpback Chub in the upper basin inhabits canyon-bound reaches with steep gradients, rapids, and coarse substrates. The river channels are comprised of hard rock substrate largely unchanged by human activity or contemporary river flow (Figure 11). All five populations inhabit roadless areas that are largely inaccessible and free of direct human alteration. The canyons and surrounding areas of upper basin populations are located in or adjacent to lands administered by the Bureau of Land Management (Black Rocks, Westwater Canyon, and Desolation/Gray canyons), the National Park Service (DNM and Cataract Canyon), and the Uintah and Ouray Indian Reservation (Desolation/Gray canyons). These canyon areas are popular whitewater boating and recreational areas, and they are protected by the rules and regulations of the appropriate agency.

Although there are no changes to the geomorphology of these canyon areas, altered flow regimes in the upper basin have modified sediment budgets, and reduced spring peaks have allowed shorelines to be invaded by nonnative tamarisk and Russian olive, but with minimal effect on canyon habitats. The only major change to historical habitat is inundation by reservoirs formed by large mainstem dams in the 1960s; one population was extirpated (Flaming Gorge/Hideout Canyon) and one was reduced in distribution (Cataract Canyon). Recent low levels of Lake Powell have exposed the historical habitat in lower Cataract Canyon that could allow for downstream expansion of the Cataract Canyon population.

Figure 11. Rocky canyon habitat occupied by Humpback Chub in Black Rocks, Westwater Canyon, Desolation/Gray canyons, and Cataract Canyon of the upper Colorado River basin.

4.1.2 Suitable River Flow and Temperature—The following is a summary of flow and temperature conditions in populations of the upper basin followed by a detailed description:

- Flow regimes have been altered for more than 75 years, most significantly in the last 50 years by flow regulation and water withdrawal, brought about by construction of mainstem storage projects and irrigation diversions in the mainstem and tributaries;
- Invasions of nonnative fishes and hybridizing Roundtail Chub into populations are correlated with reduced spring flow;
- Temperature of upper basin rivers have increased over the last 40–65 years as a result of lower stream flow, increased air temperature, and higher evaporation attributed to drought and possibly reduced snowpack;

- Persistence of populations is evidence that the species is able to complete its life history at the range of flows and temperatures currently seen in the upper basin, but relationships to life stages remain largely unquantified; and
- Written and reviewed flow and temperature recommendations help to identify and evaluate species needs. The Upper Colorado River Endangered Fish Recovery Program (UCRRP) stakeholders have made great strides in the past 15 years to implement flow and temperature recommendations and have restored important aspects of intra- and inter-annual flow variability necessary to support Humpback Chub populations.

Flow—The flow regimes of rivers in the upper basin have been altered in the last 50 years by flow regulation and water withdrawal, brought about primarily by construction of mainstem dams in the 1960s. There has been little additional flow reduction in recent years, but periods of drought have produced periods of low flow. For those areas occupied by the Humpback Chub, spring peaks (June) have been reduced and summer and winter base flows (January) have increased, as described below for the periods ending with 1961 (pre-dam era) and starting in 1962 (post-dam era) (Figure 12):

- upper Colorado River: spring peak decreased by 33% and base increased by 37%;
- Green River: spring peak decreased by 34% and base increased by 76%; and
- Yampa River: spring peak decreased by 4% and base increased by 5%.

The stream gages reflect flows for the various populations, including: (1) Colorado River near Cisco for Black Rocks and Westwater Canyon; (2) Green River at Green River for Desolation/Gray canyons; and (3) Yampa River near Maybell for Dinosaur National Monument (Yampa Canyon). Cataract Canyon is located downstream of the confluence of the Colorado and Green rivers, and receives a combination of flows and temperatures of the two rivers. There are no mainstem dams on the Yampa River and the flow regime has not changed appreciably, except for small reductions in base flow from tributary impoundments and local irrigation.

Relatively few studies (Chart and Lentsch 1999; Day et al. 2000) have been conducted on the relationship between river flow and various life stages of the Humpback Chub in the upper basin. The deep and relatively inaccessible canyons occupied by the species are difficult to sample, and the only linkages between flow and fish population dynamics are inferential and reflected in short-term adult numbers. As described in section 3.1.1, evidence of spawning in the upper basin has been reported at a wide flow range of 65–60,000 cfs, but the larvae, age-0, and juveniles are difficult to sample and identify, and the influence of flow on these life stages is not fully understood. It is believed that flows that benefit other native fishes also benefit the Humpback Chub (Muth et al. 2000). The persistence of populations in the upper basin is evidence that the species is able to complete its life history under the range of flows currently seen in the upper basin.

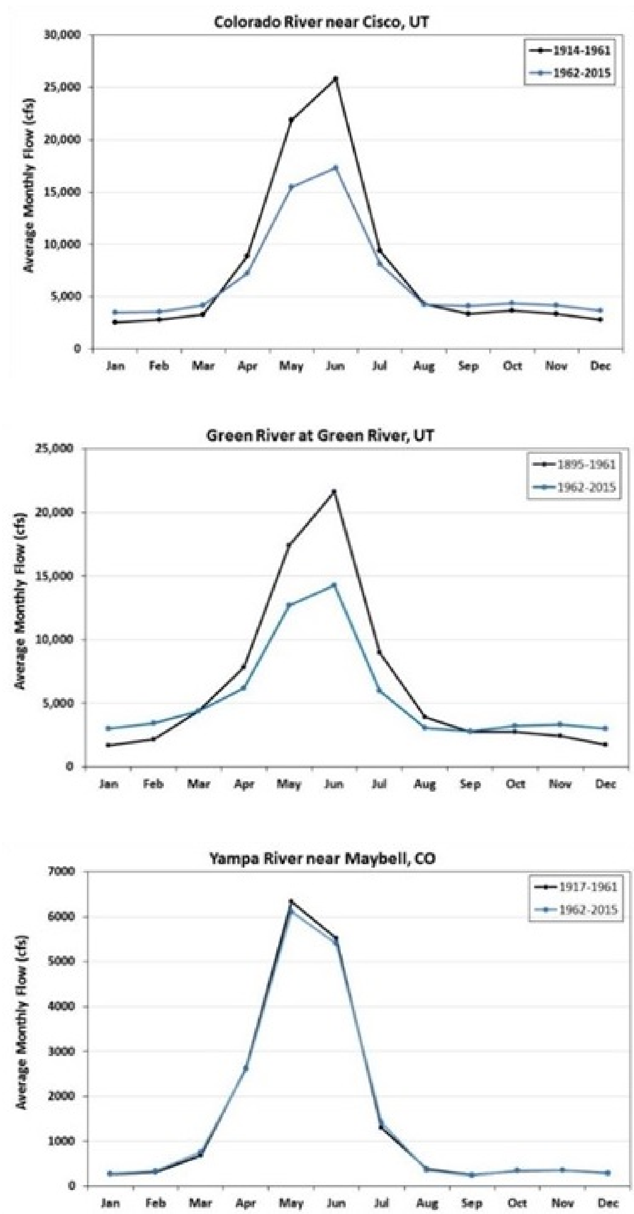

Figure 12. Mean monthly flows of the Colorado River near Cisco, UT (USGS #09180500); Green River at Green River, UT (USGS #09315000); and Yampa River near Maybell, CO (USGS #09251000) for the periods indicated. Source: http://waterdata.usgs.gov/usa/nwis/sw.

Low spring flow has been linked to increased numbers of Roundtail Chub in canyon habitats and the increased potential for competition and hybridization in the Black Rocks (Francis et al. 2016) and Westwater Canyon (Chart and Lentsch 1999) populations. High spring peaks are important for maintaining isolating mechanisms and fundamental ecological processes, including maintaining habitat diversity and minimizing invasion of other fish species, including nonnative predators. An invasion of Smallmouth Bass in the lower Yampa River and a decline in the Humpback Chub population are linked to reduced flow in 2000 (Haines et al. 2006).

UCRRP stakeholders have made great strides over the past 15 years to implement flow and temperature recommendations on the Green, Yampa, Duchesne, Colorado and Gunnison rivers with the intent of restoring aspects of a natural hydrograph (Table 4).

Temperature—Recent and ongoing drought in the Colorado River System have led to reduced stream flow, less than normal precipitation, and increased air temperature (Christensen et al. 2004; Reclamation 2012a, 2016). According to the Western Climate Mapping Initiative, mean annual air temperature during the 20th century has increased ~1.2°C in the upper basin and 1.7°C in the lower basin, which has continued into the 21st century. Temperatures of the Upper Colorado, Green, and Yampa rivers have increased over the last 40–65 years as a consequence of these weather phenomena (Bureau of Reclamation 2016).

From 1950 to 2015 (the last 65 years), cumulative daily water temperature by year (temperature degree-days) has increased ~13% in the Colorado River near Cisco, UT, 11% in the Green River at Green River, UT, and 13% in the Yampa River at Deerlodge Park, CO (Figure 13). Flow recommendations for the Green River (Muth et al. 2000), upper Colorado River (McAda 2003), and Yampa River (Roehm 2004) identify flow and temperature needed by the four native Colorado River fishes, but the effect of this temperature increase on the Humpback Chub has not been specifically investigated. Possibly, warmer temperature could lead to earlier spawning time and increased growth, but the effect on upper basin populations is largely unknown. Populations in the upper basin have persisted through historic periods of changing river flow and temperature, and it appears that the species is adapted to these types of changing environmental conditions.

The Humpback Chub is a long-lived, warm-water fish species whose many life functions are affected by water temperature, including growth. A comprehensive age-growth study of upper basin fish has not been done and the age composition of the five populations is unclear. Evidence indicates that individuals in the upper basin do not live as long as fish in the lower basin that reside in the cooler mainstem Colorado River (Meretsky et al. 2000), where their growth is slowed but longevity is apparently increased (Yackulic et al. 2014). Size and age at maturity varies with population, but generally Humpback Chub in the upper basin mature at 180–200 mm TL and at a presumed age of 3–5 years; whereas fish in the Grand Canyon take longer to mature. Individuals in the upper basin are typically smaller than fish from the lower basin, and likely produce fewer eggs. No current evidence indicates that warmer temperature has altered spawning time, growth, or any other life history function of the Humpback Chub in the upper basin.

Table 4. Flow Management Actions in the upper Colorado River System and Anticipated Effects to Humpback Chub

Flow Recommendations / Implementation	Flow Management Objectives	Flow Management - Performance Summary	HBC Target Populations	Anticipated Effects to HBC populations
Yampa River: Modde et al. 1999 / Yampa River Management Plan (Roehm 2004) & Yampa River Programmatic Biological Opinion (USFWS 2005a)	Maintain summer baseflow conditions at levels that provide fish passage for adult Colorado pikeminnow in lower Yampa River.	In 2007, UCRRP secured 5000 ac-ft in Elkhead Res. (w/ a lease option on 2000 add'l ac-ft) to augment summer base flows. Varying amounts have been used every year since 2007 in response to flow conditions.	Primary – DNM (Yampa Canyon); Secondary – DNM (Whirlpool Canyon) Desolation/Gray canyons	Augmentation water delivered to Yampa Canyon reduces the frequency and severity of periods of extreme low summer flow. The Elkhead Res. water is expected to improve UCRRP's chances of a successful repatriation of HBC in DNM.
Green River[A]: Muth et al. 2000 / Bureau of Rec. Flaming Gorge Res. Record of Decision (USDOI 2006)	Restore intra- and inter-annual flow and temperature variability from Flaming Gorge Dam downstream ~450 miles to the confluence with the Colorado River[B].	Since 2006, Reclamation has operated Flaming Gorge Dam to meet seasonal flow and temperature recommendations in virtually all years.	Primary – DNM (Whirlpool Canyon) and Desolation/Gray canyons, Secondary – Cataract Canyon	Promotes concepts of the Natural Flow Paradigm (Poff et al. 1997) expected to favor native over nonnative species. Operations to meet flow and temperature recommendations benefit native chubs in Whirlpool Canyon. Increased magnitude and duration of the spring peaks reduces influxes of nonnative Smallmouth Bass in Whirlpool and Desolation/Gray canyons.
Colorado River upstream of Gunnison confluence (15 Mile Reach): Osmundson et al 1995 / 15 Mile Reach Programmatic Biological Opinion (USFWS 1999)	Augment annual base flow and spring peak conditions to restore intra- and inter-annual flow and variability for adult Colorado pikeminnow and Razorback Sucker.	Reclamation and water users make 80-90KAF available to augment spring peak in the 15 Mile Reach by as much as 2000 cfs[C]. Baseflow augmentation occurs every year and improves summer flows by 400-500 cfs.	Primary – Black Rocks and Westwater Canyon, Secondary – Cataract Canyon	Colorado River and Gunnison River management in tandem promote concepts of the Natural Flow Paradigm (Poff et al. 1997) expected to favor native over nonnative species. Increasing the magnitude and duration of the spring peaks in Black Rocks and Westwater (and to a lesser extent in Cataract Canyon) is expected to favor Humpback Chub over native Roundtail Chub and continue to preclude invasion and proliferation of nonnative Smallmouth Bass in Black Rocks and Westwater Canyon.
Gunnison River & Colorado River below confluence : McAda 2003/ Bureau of Rec. Aspinall Record of Decision (USDOI 2012)	Same as above, but also to benefit Humpback Chub.	Reclamation has operated the Aspinall unit to achieve these objectives since 2012 and has demonstrated good performance meeting seasonal flow targets	Primary – Black Rocks and Westwater Canyon, Secondary – Cataract Canyon	

[A] Similar flow management occurs on the Duchesne River (a tributary to the Green) at a smaller scale and is not listed here. [B] Five sets of year round flow recommendations correspond to five hydrologic year types ranging from dry to wet. [C] Augmentation has occurred 10 times since 1997 under the Voluntary Coordinated Reservoir Operations (CROS).

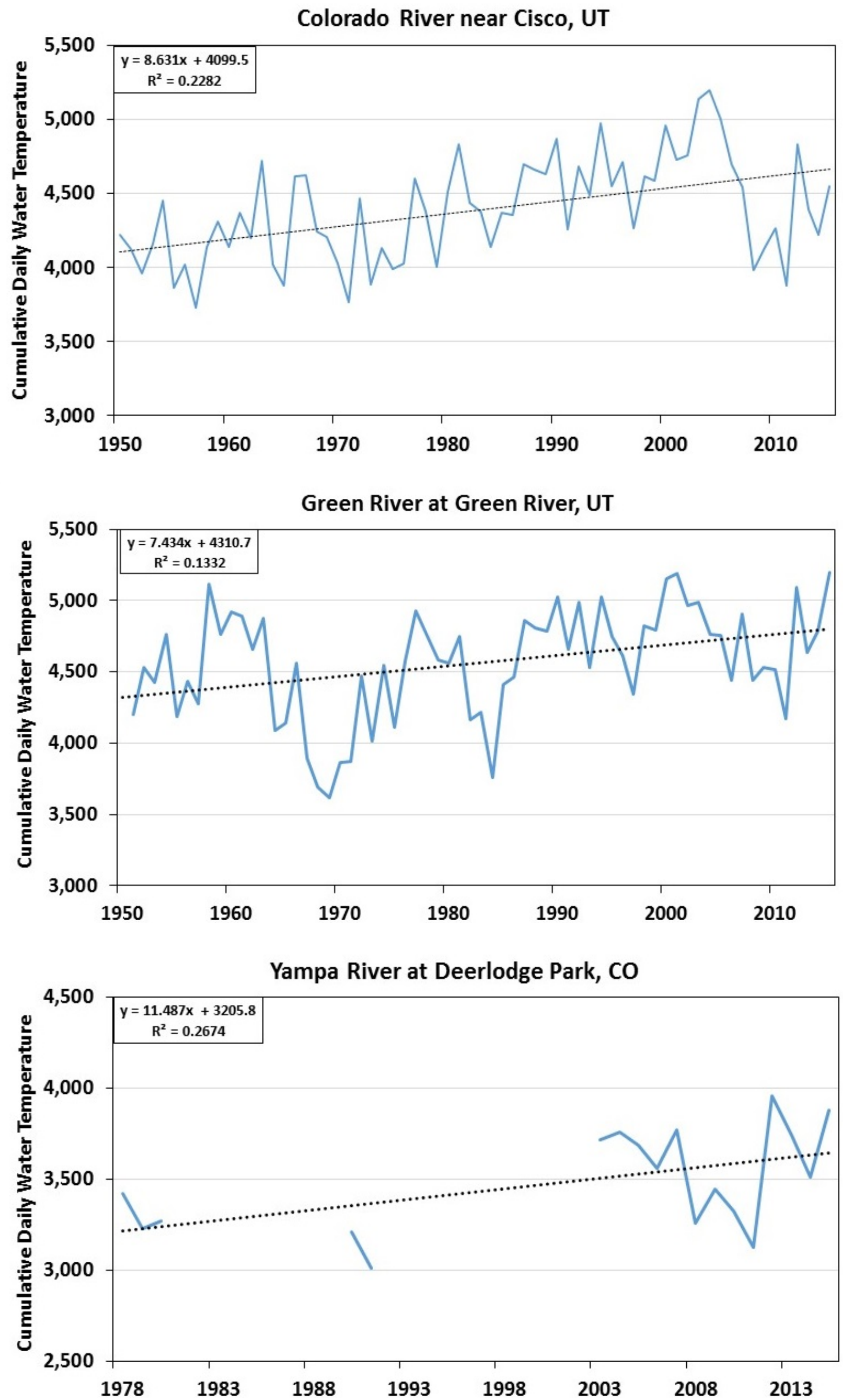

Figure 13. Cumulative daily temperature by year for the Colorado River near Cisco, UT (09180500), and the Green River at Green River, UT (09315000) from 1950 to 2015, and for the Yampa River at Deerlodge, CO (09260050) for available data from 1978 to 2015. Cumulative daily temperature is the additive of daily water temperature for each year, as an indicator of temperature degree-days (TDDs) for the year. The line of best fit represents an increase in TDDs over the period of record.

The temperature regimes of rivers in the upper basin have been changed locally by stenothermic releases from mainstem dams, although this effect does not currently extend to the upper basin Humpback Chub populations. Only the population in the Green River within DNM (Whirlpool Canyon and Island Park) has possibly been reduced by cold releases from Flaming Gorge Dam (USFWS 1990), in combination with invasion of nonnative predators, such as Smallmouth Bass. A temperature control device was installed on the dam in 1976 to warm dam releases, and native fishes (but not Humpback Chub) have recently expanded upstream into Lodore Canyon (Bestgen et al. 2006).

4.1.3 Adequate and Reliable Food Supply—The following is a summary of the food supply in populations of the upper basin followed by a detailed description:

- Mid-to low elevation rivers in the upper basin are dominated by allochthonous carbon sources that provide energy for primarily heterotrophic production;
- There is little autotrophic photosynthetic production in the main river channel because of ongoing turbidity, except at times of low flow in fall and early winter;
- The benthic community of Cataract Canyon is comprised of 23 taxa, mostly mayflies, caddisflies, and diptera that are dominated by filterer/collector species;
- Invertebrate biomass is determined by available primary carbon that is controlled by discharge patterns including large landscape floods that wash organic matter into the river; and
- Aquatic and terrestrial sources of carbon that provide food for Humpback Chub in the upper basin currently appear suitable and largely unchanged.

Humpback Chub eat a variety of foods, primarily aquatic and terrestrial macroinvertebrates. The macroinvertebrate communities of upper basin populations has been quantitatively described for Cataract Canyon (Haden et al. 2003), the Green River above and below the mouth of the Yampa River, and the lower Yampa River (Holden and Crist 1981). In Cataract Canyon, high suspended sediment inhibits primary production year-round, and the primary carbon source for benthic invertebrates is of terrestrial origin, washed into the river by large landscape floods. The invertebrate assemblage of Cataract Canyon and the Green and Colorado rivers near their confluence is dominated by three orders of aquatic insects (, EPT: Ephemeroptera, Plecoptera, Trichoptera), including 16 genera of mayflies (E), 7 genera of stoneflies (P), and 7 genera of caddisflies (T) (Haden et al. 2003). The assemblage in Cataract Canyon is comprised of 23 taxa, mostly mayflies, caddisflies, and diptera that are dominated by filterer/collector species, compared to 49 for upstream alluvial cobble bars. A smaller portion of the community is made up of predatory stoneflies and odonates (damselflies and dragonflies). In 2001, mean invertebrate biomass on cobble of the Green River was 0.41 g/m^2 ash-free dry weight, but lower in Cataract Canyon

For the Green River, 66 macroinvertebrate forms (families and genera) inhabited the reach between the Flaming Gorge Dam site and Ouray, Utah. After the dam was closed in 1962, only 52 invertebrate taxa were reported, including 38 taxa found above and below the confluence of the Yampa River (Holden and Crist 1981). Pearson et al. (1968) found that the macroinvertebrate community had not been markedly altered by Flaming Gorge Dam below the Gates of Lodore (105 km downstream), although profound changes occurred in the community near the dam. Evidently, stenothermic releases from Flaming Gorge Dam affected the macroinvertebrate community of the Green River in DNM, and combined with predation and competition from nonnative fishes (e.g., Smallmouth Bass), as well as an historic rotenone treatment (Holden 1991), led to the decline of the Humpback Chub. It is unclear if the macroinvertebrate community described by Haden et al. (2003) for Cataract Canyon is similar to that of the four other upper basin populations, but the diet of chubs examined from these populations reveals the same suite of invertebrate species. Stomach contents of juvenile *Gila* (Humpback Chub or Roundtail Chub) from Desolation/Gray canyons show that the fish fed primarily on mayflies, midges, stoneflies, caddisflies, terrestrial invertebrates, and invertebrate remains (Jacobi and Jacobi 1982).

Humpback Chub in Cataract Canyon have been observed feeding on food items from the water's surface that can change with event, indicating that the species is capable of switching diet according to available food supply (Valdez 1990). Humpback Chub feed heavily on floating material entrained in eddies and low-velocity areas, as well as on sporadic food supplies brought on by large flow events or seasonal phenomena, such as mayfly hatches, grasshopper infestations, or migrating Mormon crickets (*Anabrus simplex*; Vanicek 1967; Tyus and Minckley 1988).

The biological processes of mid-to low elevation rivers in the upper basin are dominated by allochthonous carbon sources that provide energy to primarily heterotrophic production. There is little autotrophic photosynthetic production because the river is nearly always turbid, except at times in fall and early winter. The majority of food items used by river fishes include aquatic invertebrates (primarily insects) and terrestrial insects. The ecosystem that supports these conditions appears to be largely intact in the upper basin, and the current food supply for the Humpback Chub appears to be adequate and reliable.

4.1.4 Habitat With Few Nonnative Predators and Competitors—The following is a summary of predators and competitors in populations of the upper basin followed by a detailed description:

- ~50 species of nonnative fish have been introduced into the upper Colorado River System in the last 100 years, with 18 nonnative fish species inhabiting the same areas as Humpback Chub populations;
- Smallmouth Bass, Northern Pike, and Channel Catfish are predaceous introduced fishes which have established reproducing populations in certain locations in the upper Colorado River System. Walleye and Largemouth Bass are predaceous, non-recruiting introduced fishes that exist in the river primarily from emigrating from reservoirs (or ponds);

- Channel Catfish reside and recruit in Humpback Chub population areas; Smallmouth Bass occur in a subset of Humpback Chub population areas but rarely recruit there; Largemouth Bass can occur and do not recruit in Humpback Chub population areas; Northern Pike and Walleye are rare or absent from Humpback Chub population areas;
- Smallmouth bass are common in Desolation Canyon and have apparently expanded their range downstream throughout the canyon over the last decade, are present in low densities in the Dinosaur National Monument population and in Ruby Horsethief Canyon (surrounding Black Rocks), and are rare in Cataract and Westwater Canyons;
- Annual fluctuations in Smallmouth Bass density and size structure in Humpback Chub habitats are influenced by emigration from upstream areas. Warm summer base flow from low snowpack increases Smallmouth Bass production system-wide, whereas higher spring and summer flows decrease Smallmouth Bass production;
- Channel Catish densities in Humpback Chub populations are assumed to stable over the last 50 years, potentially indicating non-deleterious sympatry with Humpback Chub. Channel Catfish popualtions are more dense in Desolation Canyon, Cataract Canyon, and DNM;
- Largemouth Bass encountered in rivers of the upper basin are do not recruit to adult size classes; most individuals encountered are less than 250 mm. Catch rates are related to flow, with increased catch after large flow years that allow Largemouth Bass to emigrate from off-channel ponds. Largemouth Bass are only encountered near Black Rocks and Westwater Humpback Chub populations; and
- Nonnative fish management is ongoing in the upper basin to reduce the impact of nonnative predators and competitors on all native fishes.

The Humpback Chub evolved in an environment relatively free of predators and competitors, and is ill-adapted to living with the many nonnative fish species that have been introduced into the Colorado River System. The Humpback Chub is a soft-rayed fish with no defense mechanisms, such as sharp scales, teeth, or spines for protection from predators. Nonnative fish first appeared in the Colorado River in the late 1800s and early 1900s, with the import of fishes from other continents and river basins as food, such as Common Carp and Channel Catfish (Miller 1961; Minckley 1991). Additional introductions of various species took place in the mid-1900s with the development of reservoir sport fisheries, such as in Lake Mead (1935), Flaming Gorge Reservoir (1962), and Lake Powell (1963).

Nearly 70 species of nonnative fish have been introduced into the Colorado River System in the last 100 years, including ~50 species in the upper basin (Tyus et al. 1982; Carlson and Muth 1989; Lentsch et al. 1996; Valdez and Muth 2005). Since the late 1990s, few additional species have been introduced, although ranges and densities of these species have shifted.

Altogether, 18 species of nonnative fish occupy the same areas as Humpback Chub; additional species are uncommon or rare in these areas. Humpback Chub populations have persisted in the presence of these nonnative fishes for about the last 50 years (Figure 14).The density of nonnative fish species in canyon-confined areas occupied by Humpback Chub is generally lower than in adjacent low gradient areas (see discussion below) because of the more arduous hydrological conditions of canyon areas (Valdez and Clemmer 1982; Chart and Lentsch 1999).

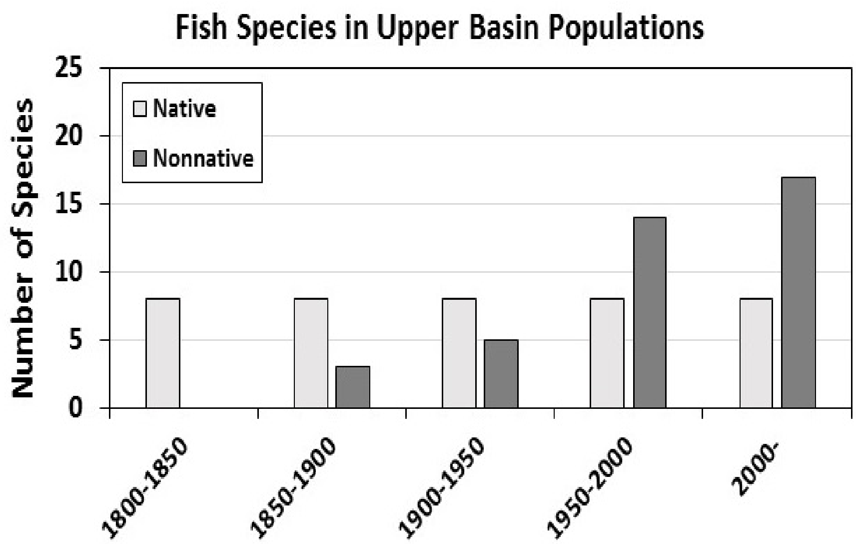

Figure 14. Numbers of native and nonnative fish species in Humpback Chub populations of the upper Colorado River basin.

In the upper Colorado River System, Smallmouth Bass, Largemouth Bass, Walleye, Channel Catfish, and Northern Pike are predatory nonnative fish of concern. Northern Pike and Smallmouth Bass are highly fecund in certain reaches of the upper Colorado River System, but typically not in Humpback Chub habitats; Largemouth Bass and Walleye are primarily emigrants from reservoirs, having not been documented as recruiting in riverine portions of the upper Colorado River System. Channel Catfish occur throughout the upper Colorado River System but are not considered predacious until they reach large adult sizes. Key ecological metrics for nonnative species of interest are shown in Table 5.

Smallmouth Bass present the highest potential impacts to Humpback Chub because the species can co-occur with Humpback Chub in certain canyon habitats and is a potential predator across its entire life history. However, canyon-bound reaches in the upper basin are not preferred habitats of Smallmouth bass, and are not characterized as Smallmouth Bass production areas, which greatly reduces the long-term sympatric density (Table 6).

Smallmouth Bass density and size structure in canyon habitats are influenced by emigration from nearby habitats rather than local production, reducing densities of Smallmouth Bass in average and wetter flow years, such as 2015 and 2016. Catch rates of Smallmouth Bass in

Humpback Chub population centers typically increase in years during or immediately following substantial nearby production, but then decline in subsequent years if nearby production is limited. This concept can be seen in the densities of Smallmouth Bass in Desolation Canyon in 2014, following the 2013 production in the middle Green River (Table 6). Similarly, densities in Ruby-Horsethief Canyon surrounding Black Rocks increased in 2013 and 2014 in response to 2013 production in the Grand Valley, but rapidly declined in 2015 and 2016. This cyclical density pattern reduces the long-term impact of Smallmouth Bass on Humpback Chub under adequate flow regimes.

Table 5. Ecological characteristics for nonnative fish of impact to upper basin populations of Humpback Chub, with a qualitative risk assessment.

	Smallmouth Bass	**Channel Catfish**	**Largemouth Bass**	**Walleye**	**Northern Pike**
Does the species recruit in riverine habitats?	Y, primarily in alluvial reaches	Y, basin wide	N, very few adult fish	N, emigrate from reservoirs	Y, in cold water reaches
Is the species sympatric with Humpback Chub?	Y, in some populations [A]	Y	Y, in some populations [B]	N, uncommon	N, rare
Does the species persist in Humpback Chub populations?	N, limited recruitment	Y, wild recruitment	N,	N, primarily migrating individuals	N, habitat & temperature unsuitable
Is the species always a potential predator to Humpback Chub?	Y, piscivores at early age	N, piscivores at larger sizes	Y, piscivores at early age	Y, piscivores at early age	Y, piscivores at early age
Humpback Chub populations of interest	Black Rocks, Desolation Canyon & DNM	All	Black Rocks and Westwater	All except DNM	DNM
Overall Risk	**Moderate/ High in DNM & Desolation; Low elsewhere**	**Low /Moderate**	**Low /Moderate**	**Low**	**Low**

[A] annually fluctuating densities of sympatry in DNM and Desolation Canyon, Rare sympatry in Westwater and Black Rocks, species absent in Cataract
[B] annually fluctuating densities of sympatry

Table 6. Smallmouth bass removal data (fish per hour and total catch) both within Humpback Chub populations (bolded) and adjacent river reaches since 2013. Effort, timing, and sizes removed may not be standardized. NR = Not reported; NS = Not sampled.

Location	River Miles	Smallmouth Bass removed per hour (Total individuals removed)				Reference
		2013	2014	2015	2016	
Yampa River						
Middle Yampa River	151 to 47.5	15.5 (10,267)	17 (11,710)	22.7 (13,074)	12.6 (7249)	Hawkins et al. 2013, 2014, 2015, 2016
Yampa Canyon (DNM population)	46 to 0	9.07 (1659)	23.7 (3966)	8.16 (1139)	8.62 (829)	Jones 2016
Yampa & Green River confluence						
Green River						
Lodore Canyon		2.7 (NR)	1.6 (38)	1.2 (26)	1.2 (27)	Bestgen et al. 2014, 2015, 2016 CPUE data provided by authors
Yampa & Green River confluence						
Whirlpool Canyon (DNM population)		7.3 (NR)	5.1 (71)	3.0 (46)	1.9 (24)	Bestgen et al. 2014, 2015, 2016 CPUE data provided by authors
Island Park	344.5 to 319.5	21.1 (5,913)	12.1 (2,768)	3.15 (787)	4.17 (1,016)	Jones & Howard 2013, Jones et al. 2014 , 2015, & 2016
Middle Green River	319.3 to 206.8	48.6 (20,210)	16.97 (5,539)	6.55 (2,738)	6.45 (2,003)	Staffeldt et al. 2016
Desolation & Gray canyons	206.8 to 128	NS	16.22 (1,626)	2.28 (286)	1.75 (69)	Jones et al. 2014, 2015, & 2016
Lower Green River	128 to 0	NR	NR	NR	(2)	Bestgen et al. 2016
Upper Colorado River						
Grand Valley	193.7 to 152.6	9.01 (2640)	2.06 (916)	1.23 (472)	1.56 (462)	Francis 2016 (data modified from Table 1)
Ruby Horsethief (includes **Black Rocks**)	152.6 to 124.8	9.10 (649)	2.53 (166)	0.72 (41)	0.42 (19)	
Westwater Canyon	124.8 to 111	NS	NS	1.19 (9)	0.39 (5)	Hines, unpublished data 2017
Cisco to Potash, Utah	111 to 47.2	0.40 (29)	0.42 (61)	0.21 (46)	0.10 (21)	Francis 2016

Channel Catish densities in Humpback Chub populations are assumed stable over the last 50 years, potentially indicating non-deleterious sympatry with Humpback Chub. Channel Catfish popualtions are more dense in Desolation Canyon, Cataract Canyon, and DNM . UCRRP experimented with Channel Catfish removal in the 1990s but determined that work to be ineffective. Crews now only remove Channel Catfish of sizes deemed predatory to large native fishes (greater than 400 mm). These individuals are captured in low densities. Catches of large Channel Catfish are typically in the single digits in Humpback Chub population areas.

Largemouth Bass encountered in the upper Colorado River do not recruit to adult size classes; most individuals encountered are less than 250 mm. Catch rates are related to flow, with increased catch after large flow years that allow Largemouth Bass to emigrate from off-channel ponds. Largemouth Bass are only encountered near Black Rocks and Westwater Humpback Chub populations.

In contrast, Walleye and Northern Pike do not typically occupy the warm-water, canyon-bound reaches occupied by Humpack Chub. Catches of these two species are low, especially when compared to other upper basin locations, such as Walleye catches in alluvial reaches (Figure 15) and Northern Pike catches in cold water reaches. Captures are characterized by adult sizes, which are presumably migrating adults.

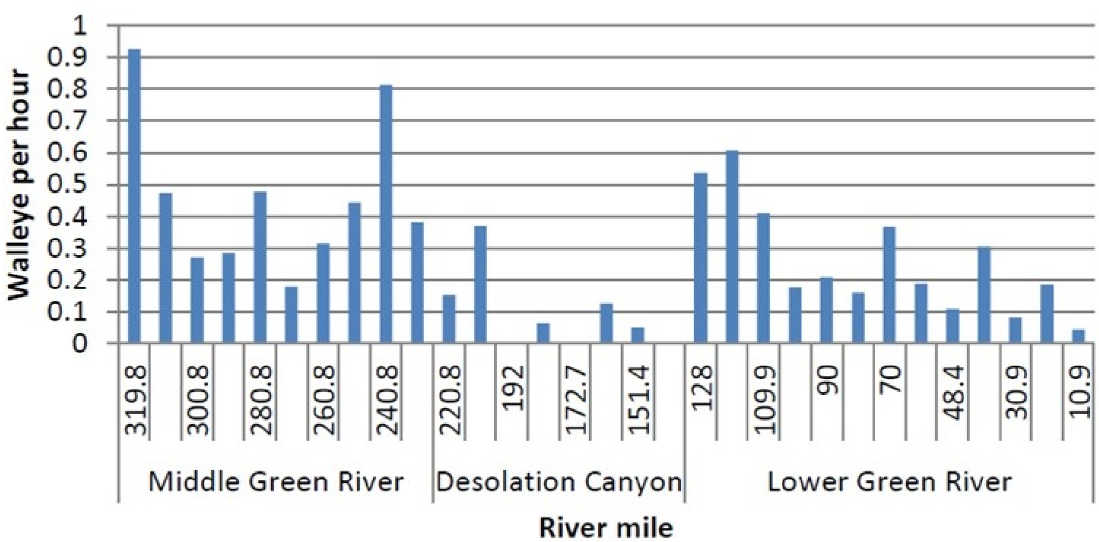

Figure 15. Catch per unit effort for Walleye on the Green River from April 9 to June 8, 2016. Figure from Michaud *et al.* (2016). The Middle Green River and the upper portion of the Lower Green River (RM 128 to 109.9) are alluvial reaches that display denser catches of Walleye.

Black Rocks—The primary species of concern in Black Rocks are Smallmouth and Largemouth Bass. In the Colorado River, Smallmouth Bass production is centered in the Grand Valley reach upstream of Humpback Chub populations. Nonnative removal in Ruby-

Horsethief Canyon (including the Black Rocks Humpback Chub population and other locations not occupied by Humpback Chub) is conducted to monitor the nonnative fish community and remove any individuals moving downstream. Catch rates from specific nonnative fish removal and monitoring of Humpback Chub indicate that densities of Largemouth and Smallmouth Bass can increase in response to upstream production, but that densities return to lower levels within a couple of years. Specifically, Smallmouth Bass in Ruby-Horsethief Canyon were consistently low from 2004 to 2012, but elevated Largemouth Bass catch rates in Black Rocks during fall Humpback Chub monitoring in 2012 (RM 7 to 78) prompted increased removal effort in subsequent years (Francis et al. 2016). Similarly, catch rates of Smallmouth Bass during nonnative removal in Ruby-Horsethief Canyon greatly increased in 2013 and 2014 (Table 6, above), potentially a result of downstream dispersal from extensive upstream production. However, Smallmouth Bass catches decreased substantially in subsequent years (78% from 2014 to 2015; and declining again in 2016) (Figure 6 from Francis 2016 and Table 6, above). Even more importantly, only three Smallmouth Bass and only 14 Largemouth Bass were removed during Humpback Chub monitoring in the Black Rocks reach occupied by Humpback Chub in 2016 (Francis and Ryden 2016).

Westwater Canyon—The primary species of interest in Westwater Canyon are Smallmouth Bass and Walleye. Smallmouth bass captures in Humpback Chub habitats downstream of Ruby-Horsethief Canyon are rare (Table 6); in 2016, five Smallmouth Bass were captured in Westwater monitoring (Hines 2016). Some nonnative removal effort does take place downstream of Westwater Canyons, primarily focused Walleye removal in spring and fall. Walleye catch rates have been declining in this reach since 2013, and most fish are captured in the Moab and Cisco reaches downstream, not in Westwater Canyon (Michaud et al. 2016). Smallmouth Bass are removed as part of this effort, but catch rates are typically low. Juvenile and adult Smallmouth Bass removal rates were less than 0.5 fish per hour every year, and declined from 2014 to 2015 to 2016 (Francis 2016). However, of concern was the fact that a localized high density of fish greater than 325 mm were collected from Cisco to Dewey Bridge, UT in 2014 and 2015, but catch rate did decrease in 2016 (Francis 2016). Northern pike are rarely caught during in-river removal near Westwater or Black Rocks, with only three captured in the upstream Grand Valley reach in 2016, and one captured near Cisco, Utah; all four were large adults (Francis 2016).

Dinosaur National Monument—The primary species of concern in Dinosaur National Monument are Smallmouth Bass, Channel Catfish, and Northern Pike. The Dinosaur National Monument population occurs in Yampa and Whirlpool canyons in the Yampa and Green rivers, respectively. Both canyons are dominated by native fish despite being in near proximity to high production areas of Smallmouth Bass and Northern Pike, indicating that habitats are not conducive to these nonnative fish. Monitoring in Yampa Canyon indicates native Flannelmouth and Bluehead Suckers have dominated the fish community over the past decade (>75% of the abundance), with Channel Catfish moderately abundant, and Roundtail Chub and Smallmouth Bass present in low abundance (Jones 2016).

Native fishes similarly dominate in Whirlpool Canyon, where 70% of all fishes collected in 2016 were native (71% in 2015) (Bestgen et al. 2016).

Catch rates of Smallmouth Bass in Yampa and Whirlpool Canyons increased in 2013 (Whirlpool Canyon) and 2014 (Yampa Canyon) in response to high production in nearby Island Park and middle Yampa reaches in 2012 and 2013 (Table 6). However, densities of Smallmouth Bass in these reaches declined to lower levels in subsequent years (Bestgen et al. 2016, Jones 2016). This demonstrates that Smallmouth Bass are not able to establish in high densities over the long term. Both Walleye and Northern Pike catch rates in the Dinosaur National Monument population are uncommon or rare. Catch rates of Walleye in Whirlpool and Yampa Canyons were lower than 0.05 fish per hour in 2016 (Table 6 and 7 in Michaud et al. 2016). Similarly, Northern Pike catch rates in Yampa Canyon averaged 12 fish per year, and have been declining since 2013[5] (Jones 2016); Northern Pike abundance in Whirlpool Canyon is low and none were captured in 2013-2016 (Bestgen et al. 2016). Neither Northern Pike nor Walleye are known to reproduce in the local area, but Northern Pike do reproduce upstream in both the Yampa and Green rivers. Walleye are likely emigrating from reservoir sources such as Red Fleet and Starvation reservoirs, which are now screened, or Lake Powell.

Desolation/Gray canyons—The primary nonnative fish of concern in Desolation and Gray canyons is Smallmouth Bass. While Smallmouth Bass have been documented in Desolation Canyon since the initial basin-wide increase in the early 2000s, Desolation Canyon is considered a limited Smallmouth Bass production area because most individuals in this reach come from upstream production areas. Walleye and large Channel Catfish are uncommon in Desolation and Gray canyons and Northern Pike are rare.

In monitoring efforts prior to 2014, Smallmouth Bass were typically encountered in lower densities than other nonnative species, such as Channel Catfish. However, catch rates were elevated in 2014 following high Smallmouth Bass production in upstream reaches in 2012 and 2013 (Table 6). Catch rates returned to modest levels in subsequent years and indicate that Smallmouth Bass recruitment has been limited since 2014 (Jones et al. 2016). The central point of concern is that Smallmouth Bass have apparently expanded their range since the mid-2000s. Recent sampling indicated that Smallmouth Bass continue to be found throughout the Desolation/Gray reach (Jones et al. 2016). After the large influx of individuals in 2014, catch rates returned to previously documented levels in 2015 and 2016, but fish produced in 2014 remain present (Jones et al. 2015).

Warm waters likely limit Northern Pike occupancy in Desolation/Gray canyons. Northern pike are a rare catch in this reach, with crews removing only one individual in each of 2014 (Jones et al. 2014) and 2015 (Jones et al. 2015), and none in 2016 (Jones et al. 2016). Walleye are of low to moderate concern in Desolation/Gray canyons. Catch rates do not

[5] Specific catches were 16, 14, 10, and 8 Northern Pike in 2013, 2014, 2015, and 2016, respectively. These data are presented in Table 2 of each annual report for the UCRRP's Project 110.

warrant targeted removal of Walleye in this reach, but continued removal during other projects is justified (Michaud et al. 2016). Walleye density is much lower in Desolation/Gray canyons compared to more low gradient reaches upstream and downstream (Figure 15). Large Channel Catfish (greater than 400 mm) are also removed when encountered, but captures of these individuals is typically less than 10 individuals per year (Jones et al. 2014, 2015, and 2016).

Cataract Canyon—Specific nonnative removal actions are not conducted in Cataract Canyon, so nonnative captures are wholly a result of Humpback Chub monitoring conducted in autumn. However, it is worth noting that Smallmouth Bass and Northern Pike are very rare below Desolation Canyon on the Green River and very rare below the Grand Valley reach on the Colorado River. Because Cataract Canyon is immediately upstream of Lake Powell, it is expected that emigrating Walleye pass through the canyon. However, Walleye catches within the canyon are rare. In 2015, no Walleye, Northern Pike, or Smallmouth Bass were captured during Humpback Chub catch per unit effort estimates (Ahrens 2015). In 2013, three Walleye were captured (Howard 2013) and no Smallmouth Bass or Northern Pike. These catch rates, combined with Cataract Canyon's low latitude and high gradient, indicate that nonnative fish do not likely occupy this population in meaningful densities.

4.1.5 Suitable Water Quality—The following is a summary of water quality conditions in populations of the upper basin followed by a detailed description:

- Many water contaminants have been identified, but the effects of these on Humpback Chub have not been specifically investigated;
- Selenium and mercury have been identified as having physiological effects on Razorback Sucker and Colorado Pikeminnow, but effects on Humpback Chub are unknown;
- Catastrophic spills of hazardous materials, such as petroleum products or other chemicals are a potential threat to water quality and to Humpback Chub;
- These types of spills have occurred in Yampa Canyon but the effect was not documented;
- Another potential catastrophic threat is ash and debris flows from large rainstorms following range fires; these have occurred in Westwater Canyon and Desolation/Gray canyons; and
- Water quality is not known to be limiting Humpback Chub populations in the upper basin.

Water Quality and Contaminants—Since 1995, the National Stream Quality Accounting Network (NASQAN) of the U.S. Geological Survey (USGS) has monitored the water quality of the Colorado River (Hart and Hooper 2000). Many contaminants have been identified, but the effect of these on the Humpback Chub has not been specifically investigated, other than what is generally known about the effect of various contaminants on fish.

Some water contaminants may incorporate into body tissue of newly-hatched larvae and cause adverse physiological effects, deformities, or death. For example, vertebral defects and spinal deformities can be caused by heavy metals (e.g., arsenic, cadmium, copper, lead, mercury, or zinc) or organochloride, and carbamate intoxications (Silverstone and Hammell 2002). Over 16% of young Roundtail Chub from the Yampa and Colorado rivers in 1981 had spinal deformities (lordosis) hypothesized to be related to high pesticide levels from local agricultural applications (Haynes and Muth 1981). No tissue analysis of Humpback Chub has been conducted to determine current levels of bioaccumulation or effects to individuals, although a low incidence of spinal deformity is reported in some populations, such as Black Rocks (Francis et al. 2016).

Selenium and mercury have been identified as having physiological effects on Razorback Sucker and Colorado Pikeminnow (Osmundson et al. 2000), but the effects of these elements have not been specifically investigated for Humpback Chub.

Catastrophic Spills— Catastrophic spills of hazardous materials, such as petroleum products or other chemicals are a potential threat to water quality and to Humpback Chub. 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. The vulnerability of these populations to toxic spills is illustrated by a pipeline rupture in the late 1980's releasing refined oil into occupied Humpback Chub habitat in the Yampa River, but the effects of this spill were not documented. 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 between Humpback Chub populations in Desolation/Gray canyons and Cataract Canyon[6].

Ash or debris flows from large rainstorms following range fires are a more natural catastrophic threat to Humpback Chub. These flows can deliver large amounts of mud, ash, and debris that can suffocate fish and macroinvertebrates; these debris flows often occur after range fires have denuded the landscape of vegetation and may contain fire retardant chemicals that could cause toxic fish effects. Such events killed unquantified numbers of Humpback Chub in Westwater Canyon in July 1989 (USFWS 2002) and in Desolation/Gray canyons in 2012 (Seeley Mountain Fire[7]). A similar event took place in Shinumo Creek of Grand Canyon in 2014 that killed or transported most fish downstream. A higher frequency

[6] (http://www.moabsunnews.com/news/article ce055ca4-e673-11e3-be35-001a4bcf6878.html)
[7] www.utahfireinfo.gov/

of drought appears to be increasing the incidence of range fires and possibly these types of ash and debris-laden floods.

4.1.6 Unimpeded Range and Connectivity—The following is a summary of connectivity among populations of the upper basin followed by a detailed description:

- Humpback Chub in the upper basin occur as four extant populations spaced 33–553 km apart, with no impediment to movement within or among populations;
- Numbers of individuals moving among populations is small, except between the most proximate populations in Black Rocks and Westwater Canyon, 33 km apart;
- There is no impediment to movement among the five upper basin populations, but transition of individuals is low and sufficient to ensure genetic exchange and diversity, but not sufficient to repopulated declined populations; and
- At a species level, Glen Canyon Dam is a barrier to movement between the upper and lower basins.

The Humpback Chub in the upper basin occurs as five disjunct populations with no impediment to movement, but with little exchange of individuals among populations, except between the most proximate in Black Rocks and Westwater Canyon. For the more distant populations, there has been a much lower exchange of individuals. From 1998 to 2011, the estimated annual probability of adults moving from Black Rocks to Westwater Canyon was 1.4% (6 of 404 adults), and from Westwater Canyon to Black Rocks was 1.8% (24 of 1,315 adults; Francis et al. 2016). These movements may be sufficient to affect recruitment and demography of the smaller Black Rocks population and there are sufficient numbers of individuals moving to ensure genetic exchange and diversity.

The STReaMS database reveals that from 1979 through 2014, a large number of Humpback Chub have been captured within population centers and a small number that have been captured or recaptured in between (Figure 16); these fish were captured under different sampling programs and with a variety of gears. Over 90% of fish captured from all programs in the upper basin have been caught within the five populations.

The database also shows that a few fish moved greater distances. Three fish moved from the Colorado River to the Green River, including one from Cataract Canyon to Desolation/Gray canyons (267 km), and one from Cataract Canyon to Bowknot Bend (103 km). Also, one fish moved from the Green River to the Yampa River (61 km), and one fish moved from the Colorado River to the Gunnison River (82 km). One Humpback Chub was detected in the Green River Canal at Tusher Wash in 2014 (tagged 2 days earlier in Desolation/Gray canyons) and one was detected in the canal in 2013 (tagged in 2010 in Desolation/Gray canyons).

Contemporary radiotelemetry and mark-recapture data show similar patterns of limited movement of Humpback Chub in the upper basin, with a few individuals making large movements. Two radio-tagged adults strayed ~10 km upstream from Black Rocks and returned to the population (Valdez and Clemmer 1982). More recently, 5 Humpback Chub were reported from the Grand Valley Water User's fish passage upstream of Grand Junction. One fish was captured in 2005, two in 2011, and two juveniles in 2017 (Francis and Ryden 2017). Also, two Humpback Chub were found dead on the upstream grates of the fish passageway in 2015. No Humpback Chub have been detected at the most downstream PIT tag antenna on the Price-Stubb dam, which indicates that the fish captured at the GVWU fish passage are from a relict population located at Beavertail Bend ~7 km upstream and first reported in 1980 (Valdez et al. 1982).

Small numbers of individuals have been captured outside of population centers, generally in enclaves of deep rocky habitat, such as in Elephant Canyon (Valdez 1990), Horsethief Canyon, and Beavertail Bend of the upper Colorado River (Valdez et al. 1982); below Bowknot Bend and in Whirlpool Canyon of the Green River (Tyus 1998); and in the Little Snake River (Wick et al. 1991). These outlying areas support persistently small numbers of Humpback Chub, but are not considered population centers.

Despite relatively long individual movements, most adult Humpback Chub display a high degree of fidelity to specific locales within their respective populations; movement of radio-tagged and PIT-tagged adults over 3 years was < 5 km (Valdez and Clemmer 1982; Kaeding et al. 1990). Of 1,552 fish (1,588 movements), 73% of recaptured fish remained within 10 miles (16 km) of their original capture location and 97% remained within 20 miles (32 km; Figure 17). Although there is no impediment to movement among the five upper basin populations, the transition of individuals appears low, and natural repopulation and demographic rescue of declined populations is unlikely.

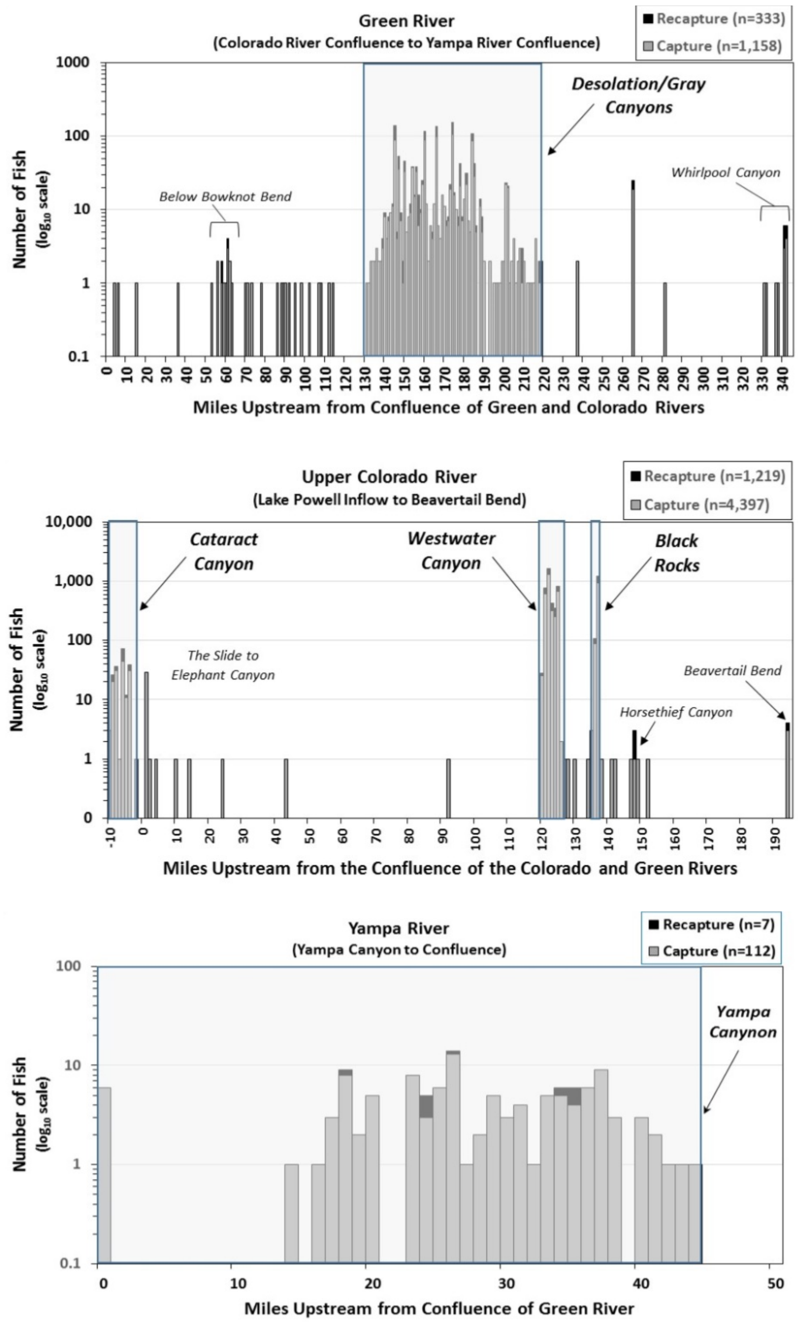

Figure 16. Distribution of Humpback Chub marked with PIT tags and recaptured or detected by remote antennas in the Green River (Colorado River confluence upstream to the confluence of the Yampa River), upper Colorado River (Lake Powell inflow upstream to Beavertail Bend, upstream of Grand Junction, Colorado), and Yampa River (Lily Park downstream to the confluence of the Green River), 1979–2014. Miles occupied by the five populations are shaded and identified. Data are preliminary from the Species Tagging Research and Monitoring System (STReaMS) database (https://streamsystem.org/), and do not include fish captured in earlier collections (e.g., Tyus et al. 1982; Valdez et al. 1982). Most tagged fish were ≥100 mm TL and the smallest fish was 68 mm TL. Numbers of fish are not adjusted for sampling effort.

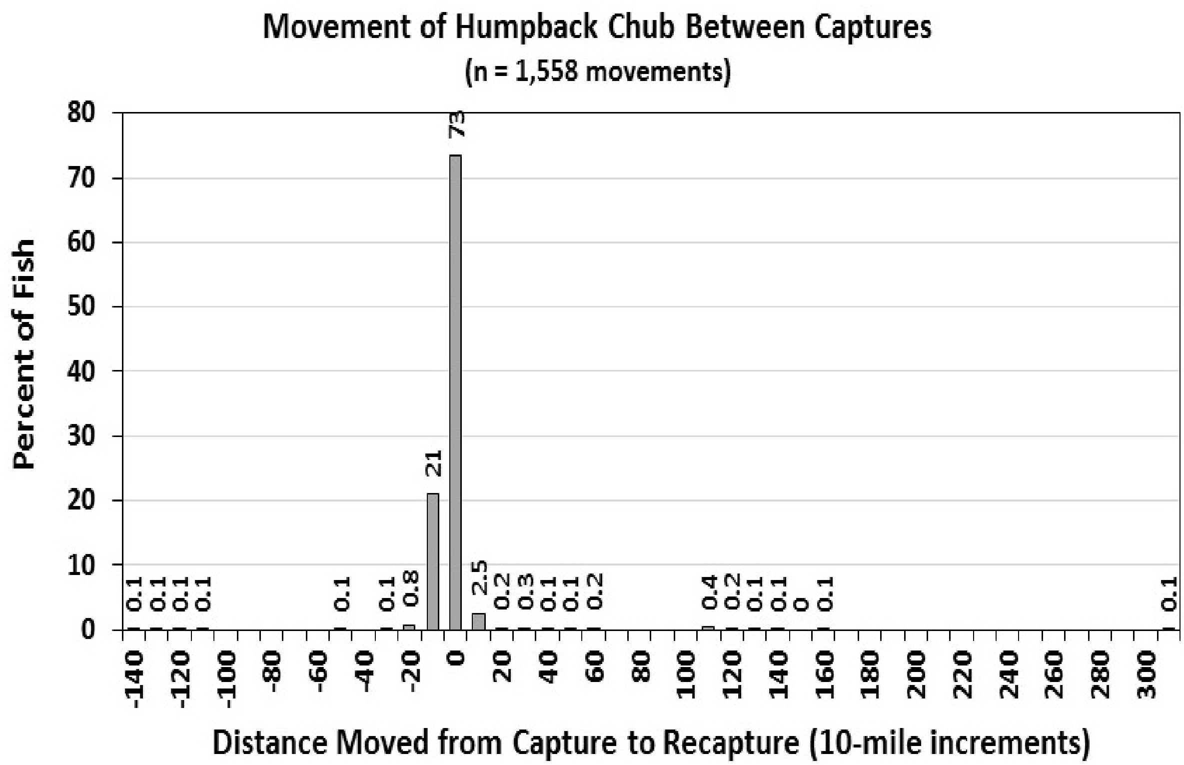

Figure 17. Movement of PIT-tagged Humpback Chub between capture and recapture locations in the upper Colorado River basin. Data are preliminary from the Species Tagging Research and Monitoring System (STReaMS) database (https://streamsystem.org/).

4.1.7 Persistent populations—The following is a summary of the populations in the upper basin followed by a detailed description (see section 4.5 for the demographic status of each population):

- Since 2007, mean sum of adults in the three upper basin populations with robust estimates is ~3,800, which is a period of apparent stability; the remaining two populations do not have recent robust estimates to report;
- The three largest populations in the upper basin supported 404 and 1,315 adults for Black Rocks and Westwater Canyon in 2012, respectively, and 1,672 adults in Desolation/Gray canyons in 2015;
- The smallest population is Cataract Canyon that ranged from 468 adults in 2003 to 295 in 2005;
- The DNM population is below detection limits and considered functionally extirpated. No Humpback Chub have been collected since 2004; and
- Four of the five upper basin populations are persisting.

Four of the five upper basin populations have persisted since they were first reported over 50 years ago, during the period 1960–1980 (Kidd 1977; Holden 1968; Valdez and Clemmer 1982; Valdez et al. 1982; Tyus et al. 1982; Tyus 1998). Adult numbers declined to about the year 2005 and have remained about the same afterward in Black Rocks, Westwater Canyon, and Desolation/Gray canyons. The population in Cataract Canyon has consisted of low numbers since it was discovered in 1979 (Valdez et al. 1982), and catch rates have not changed appreciably; the population is difficult to sample because of arduous whitewater rapids, deep-water habitats, and sparse distribution of fish (Badame 2008).

The numbers of adult Humpback Chub in upper basin populations have been monitored with mark-recapture methods starting with Westwater Canyon (1994–2012; Hines et al. 2016), Black Rocks (1998–2012; Francis et al. 2016), and Desolation/Gray canyons (2001–2015; Howard and Caldwell 2017). Estimates are done annually for two consecutive years followed by two years with no estimates to reduce handling and stress to the fish; estimates are staggered across populations because of personnel and budgetary constraints. Since 2007, mean sum of adults in the three upper basin populations with robust estimates is ~3,800, which is a period of apparent stability. The remaining two populations do not have recent robust estimates to report. The numbers of individuals in upper basin populations have varied over time, with the three largest populations most recently supporting 404 and 1,315 adults in Black Rocks and Westwater Canyon in 2012, respectively, and 1,672 adults in Desolation/Gray canyons in 2015. The smallest populations are in Cataract Canyon with 468 adults in 2003 to 295 in 2005, and in Yampa Canyon of the DNM population with 320 adults in 2001 to 224 in 2003. Individuals have not been collected in the DNM population since 2004 and it is therefore considered functionally extirpated.

The population in DNM has recently been restricted to the lower Yampa River where it appears to have declined with few fish remaining. In 2007, ~400 juvenile *Gila* spp. were taken from near Mantle's Ranch in Yampa Canyon for the purpose of establishing a refuge population (Upper Colorado River Endangered Fish Recovery Program 2009). About 200 live fish were transported each to the Ouray National Fish Hatchery, Ouray, Utah, and to the J.W. Mumma Aquatic Species Restoration Facility, Alamosa, Colorado. After the fish were large enough to identify, it was determined from visual morphological examination that there were no Humpback Chub in the sample (Melissa Trammell, National Park Service, Personal Communication, July, 2016). A sample of 28 specimens each subjected to msat DNA analysis were found to be genetically identical to the Roundtail Chub of that population, and no evidence of *G. cypha* was found in the Yampa Canyon samples (Bohn 2016). Subsequent sampling in Yampa Canyon has yielded few Humpback Chub (Jones 2012, 2013, 2014), but additional sampling is needed to determine the number of individuals that remain.

The Humpback Chub has not been translocated in the upper basin, but has been introduced from hatchery stocks once. In December of 1981, a total of 7,600 juvenile Humpback Chub were hatched and raised at the Willow Beach National Fish Hatchery and released in Cataract Canyon at 1½ years of age (Valdez 1990). These fish had been hatched from eggs taken from ripe fish in Black Rocks in May 1980 (Arcadio Gonzales-Valdes, University of Mexico at Monterey, Personal Communication, October, 1980). Each released fish was marked with a coded wire nose tag, but fish caught in subsequent investigations have not been examined with a metal detector, and the survival, fate, and eventual influence of these fish on the population size and genetics of the Cataract Canyon population is unknown.

4.1.8 High Genetic Diversity—The following is a summary of the genetic diversity of populations in the upper basin followed by a detailed description:

- Ongoing hybridization between Humpback Chub and Roundtail Chub currently occurs in all five upper basin populations;
- Three genetic subgroups were identified for Humpback Chub in the upper basin, including one for Desolation Canyon, one inconclusive determination for DNM (Yampa Canyon), and one for all other populations; and
- The current genetic status of the Humpback Chub in the upper basin shows four of the five populations linked genetically over a decadal scale, each population reflects the suite of alleles and diversity representative of the species collectively.

Douglas and Douglas (2007) identified three genetic subgroups for the Humpback Chub in the upper basin, including one for Desolation Canyon, one inconclusive determination for Yampa Canyon, and one for all of the other populations (see section 2.4). The msat DNA showed evidence of genetic exchange among groups of fish at a decadal scale, with no significant differences in genetic diversity. Recent preliminary molecular analysis indicates that upper basin populations are diverse (except for Yampa Canyon) with no change in diversity in the last 10 years and no need for supplementation with lower basin genetics (Bohn and Wilson 2017). Bohn (2016) used msat DNA analysis and found no evidence of *G. cypha* in the Yampa Canyon samples taken in 2007, although the number of specimens was small (n = 24) and it could not be determined if *G. cypha* have disappeared from the Yampa River, or if they were simply not sampled in the study.

Ongoing hybridization between the Humpback Chub and Roundtail Chub occurs in all five upper basin populations; the number of Bonytail in the upper basin is small, but the species is being stocked annually, increasing the chance of hybridization with the two other *Gila* species. The proportions of species and intergrades from past collections provide a perspective of the level of hybridization in upper basin populations.

Recent studies show that in Black Rocks, the proportion of Humpback Chub and fish with morphologic characteristics of both Humpback Chub and Roundtail Chub compared to the proportion of Roundtail Chub has declined dramatically from 55:45 (average ratio for 1979–1981, 1983–1985, 1988, and 1991; USFWS 2002) to 9:91 in 2007–2008, and 20:80 in 2011–2012 (Francis et al. 2016). These proportions reflect increased abundance in Roundtail Chub, as trammel net catches of Humpback Chub and *Gila* species combined have remained fairly stable in 2007 (8.3%), 2008 (5.4%), 2011 (9.1%), and 2012 (8.8%).

The increased abundance of Roundtail Chub is thought to be related to years of low river flow, especially during spring runoff (Kaeding et al 1990; Chart and Lentsch 1999; Francis and McAda 2011), as low flow reduces water velocity and the arduous conditions that otherwise help to impede invasion of fish species into Humpback Chub populations. This relationship is further explained in Appendix B.

4.2 Lower Basin Current Resource Conditions

4.2.1 Diverse Rocky Canyon River Habitat—The following is a summary of rocky canyon habitat in the population of the lower basin followed by a detailed description:

- The species currently occupies rocky canyon habitat in ~406 km of the Colorado River through Marble and Grand canyons, and in ~24 km in the lower LCR, as well as lower Havasu Creek into which fish were translocated;
- The mainstem river channel is largely intact and without direct human effect, but Glen Canyon Dam has reduced sediment in the mainstem;
- The geomorphic framework of the lower LCR and Havasu Creek are also intact and located in remote areas with little direct human effect;
- Riverine habitat is expanding in western Grand Canyon, as Lake Mead has receded and eroded lake sediments, exposing the historical rocky channel; and
- Rocky canyon habitat in the Grand Canyon is on lands administered by Grand Canyon National Park and adjacent to Navajo, Hope, Hualapai, and Havasupai lands that protect the current condition of these areas.

The Humpback Chub in the lower basin currently occupies ~400 km of the Colorado River through Marble and Grand canyons, as well as the lower LCR and Havasu Creek. Talus shorelines and large recirculating eddies and deep pools are used by the species in the mainstem, and rocky channels with deep pools and riffles are used in the tributaries (Figure 18). This geomorphic structure is intact and largely unchanged, except for reduced sediment in the mainstem that is retained in Lake Powell; sediment downstream of Glen Canyon Dam is delivered by tributaries, principally the LCR and Paria River. Reduced flow magnitude has allowed an encroachment of shoreline vegetation, although these changes have not affected the species, except where vegetation has reduced backwater habitat (Stevens et al. 1997).

The Humpback Chub was once distributed downstream to the confluence of Spencer Creek (RM 246; Bookstein et al. 1985), but this lower end of the canyon was inundated by Lake Mead after Hoover Dam was constructed in 1936. Since 2002, the lake has receded and exposed historical habitat that is being increasingly occupied by the species.

The Grand Canyon region is on lands administered by Grand Canyon National Park, as well as the Navajo, Hope, Hualapai, and Havasupai tribes. These serve to protect the current condition of resources in the Grand Canyon. Natural and cultural resources are further protected by the Grand Canyon Protection Act of 1992 (Title XVIII, Section 1801) that has established the Glen Canyon Dam Adaptive Management Program (GCDAMP) as a Federal Advisory Committee to the Secretary of the Interior. The GCDAMP includes 23 stakeholder groups and a research branch (Grand Canyon Monitoring and Research Center) dedicated to advising the GCDAMP on protecting canyon resources through scientific investigation.

Figure 18. Rocky canyon habitat used by Humpback Chub in Grand Canyon, including debris fans and recirculating eddies in the mainstem Colorado River, talus shorelines in the mainstem, the mouth of the LCR, and travertine dams with deep pools in the LCR.

4.2.2 Suitable River Flow and Temperature—The following is a summary of flow and temperature conditions in the population of the lower basin followed by a detailed description:

- Flow and temperature of the Colorado River through the Grand Canyon have been altered by the closure and operation of Glen Canyon Dam starting in 1963;
- Despite flow change, the species continues to use the mainstem for all life stages, except spawning, egg incubation, and larval development, which occur primarily in the LCR;
- Juveniles are able to use available shoreline habitat under the range of allowable dam releases and a daily flow change of up to 8,000 cfs;
- Adults appear to adjust to changing flow conditions under large controlled floods of up to 45,000 cfs;

- Temperature of the river has been transformed from a range of 0–30°C, to a cooler, narrower range of 7–12°C during 1974–2003, and 8–16°C after 2004;
- In cold mainstem conditions, Humpback Chub occupy areas adjacent to seasonally-warmed tributaries and mainstem habitat near warm springs;
- Starting in 2004, temperature of water released through Glen Canyon Dam increased in summer and fall to 16ºC; temperature increase enhances growth of Humpback Chub, but may also allow for invasion and expansion of warm-water nonnative fish species;
- Cold mainstem temperature has resulted in better adult body condition, lower incidence of parasites and diseases, greater longevity, and possibly faster recovery from spawning; and
- Reduced turbidity in the mainstem exposes the Humpback Chub to a higher risk of predation by sight feeders such as Rainbow Trout and Brown Trout.

Flow (Colorado River)—Flow of the Colorado River through the Grand Canyon has been altered by Glen Canyon Dam since 1963 (Figure 19). Spring peak flow at Lees Ferry (June) has decreased by ~80% from over 120,000 cfs to ~25,000 cfs, and base flow (January) has increased by ~67% from ~3,000 to 5,000 cfs (Figure 20).

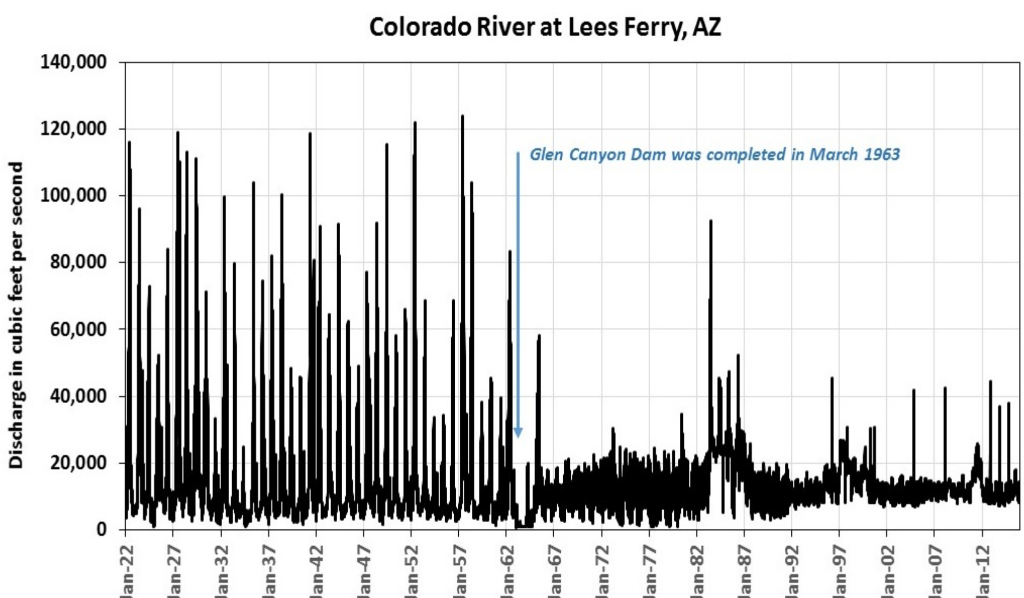

Figure 19. Mean daily discharge in cubic feet per second of the Colorado River at Lees Ferry (RM 0) before and after closure of Glen Canyon Dam, from 1922 to 2015. Glen Canyon Dam was completed in March 1963. Data from USGS site: Colorado River at Lees Ferry 09380000.

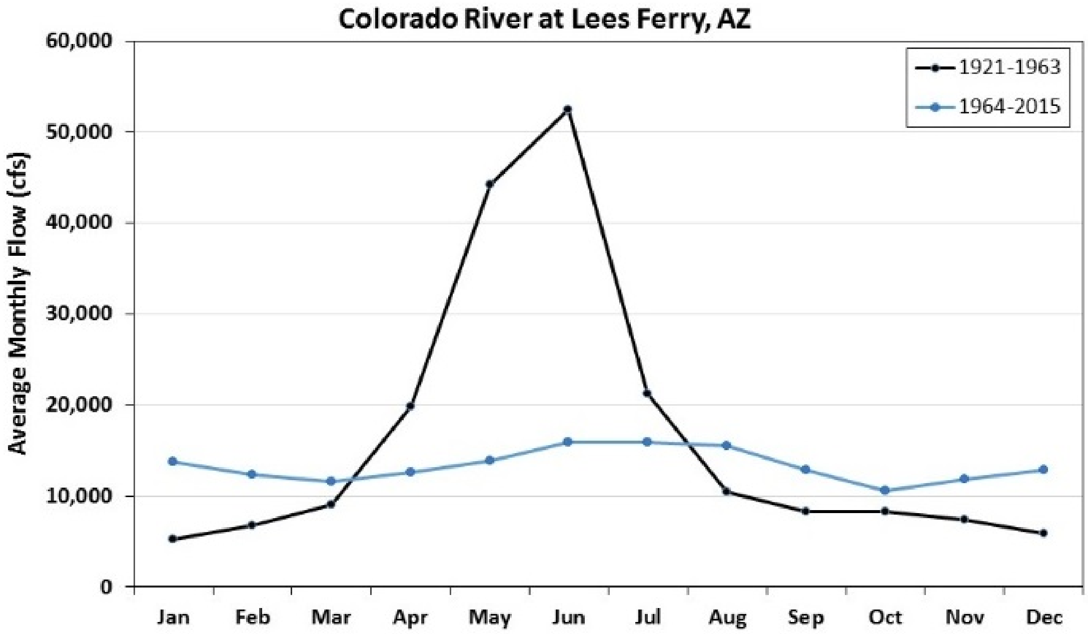

Figure 20. Mean monthly flows of the Colorado River at Lees Ferry for 1921–1963 (pre-Glen Canyon Dam) and 1964–2015 (post-Glen Canyon Dam). Data from USGS site: Colorado River at Lees Ferry 09380000.

Despite changes in flow and temperature, the Humpback Chub has continued to use the mainstem for all life stages, except spawning, egg incubation, and larval development, which take place mostly in the seasonally-warmed LCR. Adults use deep pools and recirculating eddies where food is entrained, and juveniles occupy a suite of shoreline habitats under the range of allowable flow change of up to 8,000 cfs per day (Converse et al. 1998; Korman et al. 2004).

Juveniles have shown no significant differences in survival or growth after 2 months of approximately steady fall flows, compared to daily fluctuations (Finch 2012). Adults appear to adjust to changing flows under large controlled floods of up to 45,000 cfs (Valdez and Hoffnagle 1999), and move freely to and from spawning sites under varying flows (Valdez and Ryel 1995), among mainstem aggregations and tributaries (Paukert et al. 2006), and between large eddy complexes with low velocity for low-energy feeding (Gerig et al. 2014).

Temperature (Colorado River)—The Colorado River through the Grand Canyon is stenothermic and cold because of releases through Glen Canyon Dam from the hypolimnetic layer of Lake Powell (Gloss et al. 2005; Melis 2011). The temperature regime of the once seasonally-warmed river has been transformed from a range of 0°C to 30°C, to a much narrower range of 7°C to 12°C during 1974–2003, and 8°C to 16°C after 2004 (Figure 21). Prior to 2004, Humpback Chub in the mainstem occupied areas with seasonally-warmed tributaries and warm springs (Valdez and Ryel 1995), but after 2004, the fish are increasingly occupying areas with suitable rocky complex shoreline habitat (Persons et al. 2015).

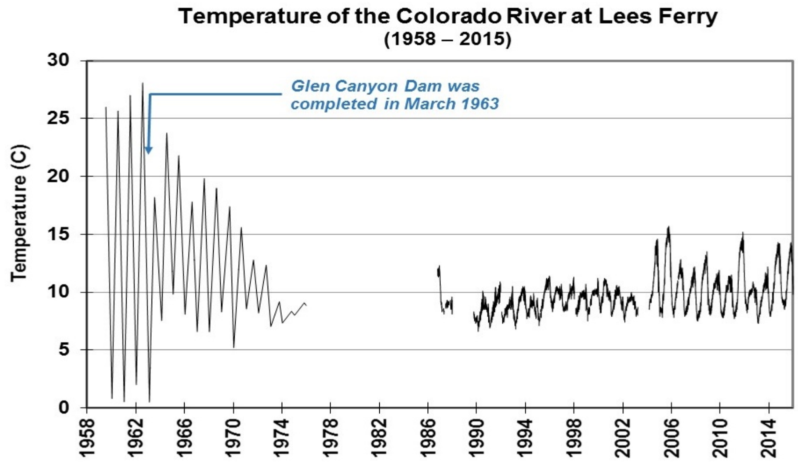

Figure 21. Temperature of the Colorado River at Lees Ferry before and after closure of Glen Canyon Dam, from 1958 to 2015. Glen Canyon Dam was completed in March 1963. Data from USGS site: Colorado River at Lees Ferry 09380000.

The Humpback Chub is an obligate warm-water species and although cold dam releases have impeded successful spawning in the mainstem, the species continues to live in the mainstem and use primarily the seasonally-warmed LCR for spawning, egg incubation, and larval development. Valdez and Ryel (1995) found a high proportion of adult Humpback Chub in the mainstem with spawning coloration and nuptial tubercles in May and June, indicating that sexual development was taking place at about the same time as fish in the upper basin, despite the cold water temperature. Brizendine (2016) used ultrasonic imaging to determine that female Humpback Chub are able to produce eggs in the mainstem Colorado River and that internal egg development and egg production likely do not limit recruitment, but females may never experience the environmental trigger(s) for spawning.

Humpback Chub in the mainstem grow slower than in the LCR (Pine et al. 2017). At a mainstem temperature of 10°C, there is no growth of larvae (Robinson and Childs 2001), and a growth rate of only 2.3 mm/30 days for age-0, compared to 10.6 mm/30 days at 20°C in the seasonally-warmed LCR (Lupher and Clarkson 1994; Clarkson and Childs 2000). Warmer water in Grand Canyon may increase Humpback Chub growth while limiting Rainbow Trout growth and thus reduce the number of days that juvenile Humpback Chub are vulnerable to predation by Rainbow Trout (Paukert and Petersen 2007).

The cold mainstem slows fish growth, but may also promote longevity. Humpback Chub that rear in the mainstem live ~5 times longer than fish in the LCR, but may take more than twice as long to reach adulthood and are ~40% less likely to survive to adults (Yackulic et al. 2014). Although fish in the Grand Canyon may live up to 40 years with greater spawning opportunity, the reduced survival rate may offset any benefit to reproductive potential. Conversely, fish that are life-long residents of the LCR grow quickly to adulthood (3–4 years) and have shorter life expectancies as adults (<20 years).

The current temperature regime of the Colorado River in the Grand Canyon may provide an overall benefit to the Humpback Chub. The cold water provides adults with better body condition (Meretsky et al. 2000; Didenko et al. 2004), a lower incidence of parasites and diseases (Hoffnagle et al. 2006), greater longevity, and possibly faster recovery from spawning (Yackulic et al. 2014). The present condition of Humpback Chub in Grand Canyon may be lower than previously reported in 2000, possibly because increased numbers of fish may be limiting space and food (Dzul et al. 2017).

Starting in 2004, the temperature of water released through Glen Canyon Dam increased in summer and fall when lower levels in Lake Powell allowed warm surface water to be entrained in the penstocks. Warmer releases of up to 16°C were reported in late summer and fall through 2015, but the magnitude and duration of these warm water releases have varied by year. This temperature increase has enhanced the growth of Humpback Chub in Grand Canyon and allowed greater mainstem residence and possibly reproduction in western Grand Canyon (Kegerries et al. 2016; Rogowski et al. 2017). The warmer temperature may also allow for expansion of warm-water nonnative fish species.

Pine et al. (2017) found biologically important differences in growth of Humpback Chub in the Grand Canyon for the 1980–1998 epoch (1), compared to the 2001–2011 epoch (2); slower growth occurred in the Colorado River in epoch 1 than in epoch 2 (because of higher reservoir levels and colder releases in epoch 1), and there was slower growth in the Colorado River compared with the Little Colorado River for all time periods. However, Hayes et al. (2017) and Finch et al. (2015) found slower growth of juvenile Humpback Chub in the Colorado River for the warm year of 2011 compared to epoch 1, and attributed the different to food limitation in 2011.

Turbidity (Colorado River)—Water turbidity is identified as cover for Humpback Chub from predators and for safe movement and feeding. The species is adapted to high turbidity, and relies on sporadic floods to deliver food and on the associated turbidity for cover while feeding. But the species also moves more frequently and greater distances under low light conditions, such as during crepuscular periods or at night (Valdez and Ryel 1995). This adaptation may be in response to the nearly constant historical turbidity, or to a more recent learned behavior to escape sight predators.

The historically turbid Colorado River in Grand Canyon was transformed into a river with high water clarity after completion of Glen Canyon Dam in 1963 (Figure 22). Virtually all of the sediment carried by the river settles to the bottom of Lake Powell and the only source of sediment is tributaries within the canyon, primarily the Paria River and the LCR (Melis 2011). Lower sediment budget and reduced turbidity in the mainstem expose the Humpback Chub to a higher risk of predation by sight feeders such as Rainbow Trout and Brown Trout (Valdez and Ryel 1995; Yard et al. 2011; Ward and Morton-Starner 2015).

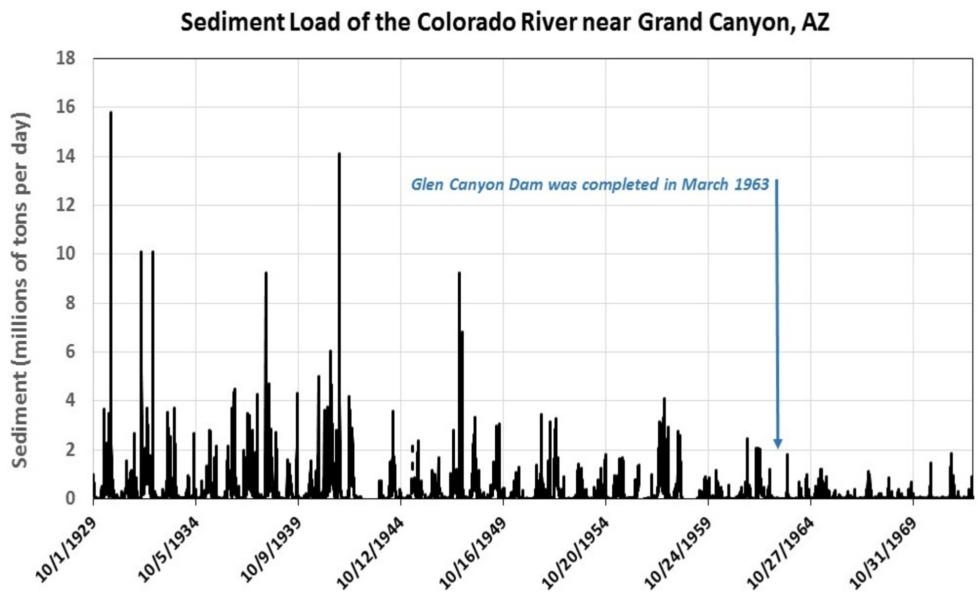

Figure 22. Sediment load of the Colorado River near Grand Canyon, AZ, before and after closure of Glen Canyon Dam, October 1, 1929 to September 30, 1972. Glen Canyon Dam was completed in March 1963. Data from Colorado River near Grand Canyon (09402500).

Flow (Little Colorado River)—The Little Colorado River is an important stream for the Humpback Chub in the Grand Canyon. The lower 12.9 km (8 miles) is designated critical habitat, and is the principal spawning area for the species in the Grand Canyon. The LCR provides habitat and food for the core population of the Grand Canyon. Although many young chub descend to the mainstem, there is a resident group of fish that spends their entire lives in the LCR (Yackulic et al. 2014).

The LCR was once a perennial stream throughout its course, except in years of severe drought (Morgan 1995). The Humpback Chub and other river fish once had access to the LCR up to Grand Falls, over 160 km upstream from the confluence of the Colorado River (Minckley 1973); the holotype for the Bonytail (*Gila elegans*; Girard 1856) is from the Zuni River, a tributary of the Little Colorado River in New Mexico, well upstream of Grand Falls. Apparently, at very high flows, fish from the mainstem Colorado River, including the Humpback Chub, could have historically accessed most of the LCR and its tributaries.

Dams and water depletions for municipal, agricultural, and industrial uses have transformed the LCR into an intermittent and highly variable stream with perennial flow only in the upper reaches of the watershed and in the lower 21 km below the Blue Springs complex. During much of the year, there is no surface flow in the middle and lower LCR above Blue Springs. Mean annual discharge of the LCR above Blue Springs is 219 cfs, as measured near Cameron (U.S. Geological Survey [USGS] Station 09402000, 1948–2007), but the flow is intermittent and varies considerably within and between years. Snowmelt runoff from the San Francisco Plateau and the Mogollon Slope in the southern portion of the watershed provides the majority of surface flow in spring. The maximum instantaneous flow of 119,913 cfs occurred in spring 1954 (Hereford 1984), and the highest mean daily discharge of 18,400 cfs occurred in October of 1972 (USGS Station 09402000, 1948–2007) as a result of an early winter storm.

Periodic high flows serve to scour the LCR of accumulated sediment and to break up some of the travertine that builds up over time as a result of the calcium carbonate precipitate characteristic of the stream. Strong year classes of Humpback Chub have been related to high spring flow in the LCR, indicating that high flows cleanse marl, sediment, and precipitate from the system, stimulate food production, and enhance survival of eggs and larvae (Gorman and Stone 1999). In recent years, the mean daily discharge of the LCR has continued to decline after 1978 (Figure 23). Both the base flow provided by Blue Spring, and the periodic high spring flows provided by snow-melt runoff are important in maintaining suitable spawning condition for Humpback Chub in the LCR.

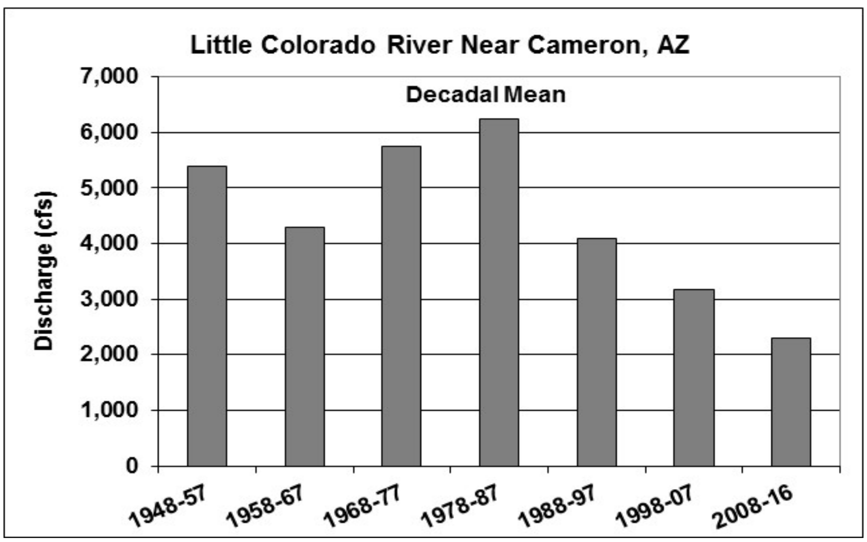

Figure 23. Mean daily discharge by decade of the Little Colorado River near Cameron, AZ, 1948–2007. Data from Little Colorado River near Cameron (USGS 09402000).

The Humpback Chub in the lower LCR is entirely reliant on flow from the Blue Springs complex for base flow, when there is otherwise no surface flow. Approximately 90% of the discharge for Blue Springs is from springs located between 16 and 21 km upstream of the confluence with the Colorado River (Cooley 1976). Flow volume of the Blue Springs complex has remained relatively constant during the last six decades. Cooley (1976), using data from Johnson and Sanderson (1968), reported an average discharge of 223 cfs for the period 1950–67, while Arizona Department of Water Resources reported 101,000 gallons-per-minute (226 cfs) between 1950 and 1993 (ADWR 2009b). A more recent estimate of discharge for Blue Springs is 237 cfs (Hart et al. 2002). The disparity in flow is unexplained and possibly related to measurement error or variation in spring discharge and not to human influence.

Over 99% of the Blue Springs complex discharges from a multiple aquifer system within the Redwall and Muav Limestones coming primarily from the Coconino (C) aquifer, a large underground aquifer that underlies much of the LCR Basin (Cooley 1976). In the area of the LCR canyon, the Coconino aquifer drains downward into the Redwall-Muav (R) aquifer via fractures through the Coconino, Hermit, and Supai formations. Once reaching the Redwall and Muav limestones, the water moves through solution channels and along fractures (Cooley 1976; ; Bills et al. 2016). Water issuing from the Redwall Limestone discharges primarily into Blue Springs in the lower LCR and into Havasu Springs in Havasu Creek, along with a few smaller springs and seeps arising along the south rim of the Grand Canyon.

The Coconino aquifer underlies ~14 million acres of the LCR Basin, and regional contributions from the aquifer to the Blue Springs complex vary. The Blue Springs area is considered the primary groundwater drain from the Little Colorado River Basin, although the primary source of the water is not well known (Hart et al. 2002; ADWR 2009b). The San Francisco volcanic field is able to contribute more of the water discharged at the Blue Springs complex than the eastern portion of the basin because of much higher precipitation and recharge rates, and because of secondary permeability imparted by the many faults and fractures in the area.

The aquifer that discharges water to the Blue Springs complex is coming under increasing demand. There is a considerable amount of groundwater pumping that draws water from the Coconino aquifer, and this pumping could affect the flow of the Blue Springs complex and reduce flow in the lower 18 km of the LCR that is currently a critical component of Humpback Chub habitat in the Grand Canyon. A similar reduction in discharge could occur in Havasu Springs that could result in reduced habitat in Havasu Creek, the location of a recent successful translocation of Humpback Chub. Effects of groundwater reduction in the Coconino aquifer may not be easily or immediately detected because of the slow response at Blue Springs, due to the large distance between areas of greatest recharge at high elevation and the Colorado River, as well as the relatively large storage and low transmissive of the aquifer (Pool et al. 2011).

Water emitting from Blue Springs is highly mineralized with sodium, calcium, chloride, and bicarbonate salts. The spring has a total dissolved solids (TDS) of 3,960 mg/L, with chloride composing 1,910 mg/L (Johnson and Sanderson 1968). The combination of these minerals imparts a milky blue or turquoise color to the water at base flow. Water from Blue Springs is 20°C and has a high free carbon dioxide (CO_2) level of 571 mg/L (Robinson et al. 1995), which precludes fish from using the area near the springs. As the water flows downstream, carbon dioxide gases dissipate into the atmosphere and calcium carbonate (calcite) precipitates as tufa, forming small travertine dams (Robinson et al. 1995). The calcite precipitate increases turbidity, imparts a milky color to the water, and covers the stream bottom with a layer of unconsolidated whitish particles. The Humpback Chub is among the few fish species able to live and reproduce in the water of the LCR and Havasu Creek; other species that are predators or competitors (e.g., Channel Catfish, Rainbow Trout, and Brown Trout) live in these tributaries, but in small numbers with little or no reproduction.

The adaptability of the Humpback Chub to varied and rigorous environments and the species' ability to transition at will between the seasonally-warmed LCR and the colder, less saline Colorado River is on full display in the Grand Canyon. The species is able to carry out all of its life functions in water with a flow range of 237–120,000 cfs, a temperature range of 8–25°C, a TDS concentration of nearly 4,000 mg/L (seawater = 40,000 mg/L, brackish water = 10,000 mg/L), and a chloride concentration of nearly 2,000 mg/L (seawater = 18,980 mg/L). Adults have been observed spawning in the LCR at a flow range of 250–19,775 cfs, and individuals are able to persist during large floods with high sediments loads.

It is uncertain how or when continued pumping and withdrawal of water from the Coconino Aquifer will affect flow of the Blue Springs complex, but reduced base flow in the LCR could negatively affect the Humpback Chub through reduced stream capacity, spawning potential, survival, growth, and food production. Reduced base flow could also allow for a build-up of travertine in the LCR that could further reduce available space and habitat for the various life stages of the Humpback Chub.

Temperature (Little Colorado River)—The temperature of the LCR varies seasonally from a low of ~10ºC in winter to a high of ~25ºC in summer (Figure 24). This provides a seasonal temperature regime in which the Humpback Chub evolved with suitable spawning temperature in spring and summer for spawning, egg incubation, and larval development.

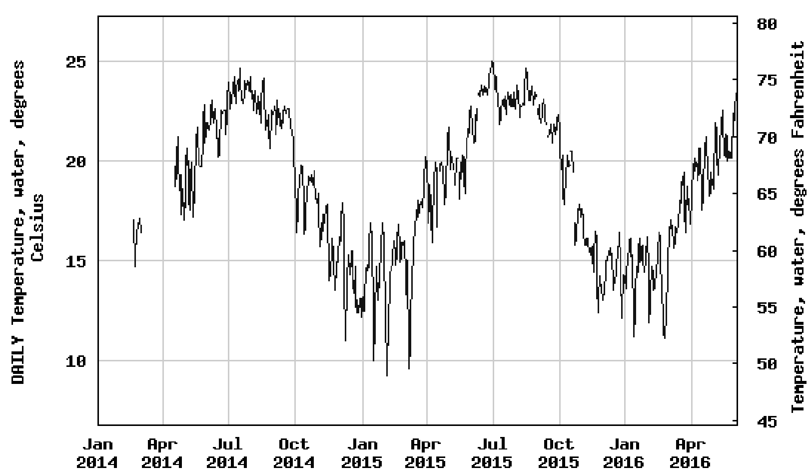

Figure 24. Mean daily temperature of the Little Colorado River above the mouth near Desert View, AZ, 2004–2016. Data from Little Colorado River above the mouth near Desert View (09402300).

Despite large changes in basin hydrology, the seasonal temperature regime and a steady base flow provided by the Blue Springs complex provide a stable and reliable habitat for the

Humpback Chub. Seasonal warming provides a cue for spawning, and the warm sheltered habitat of the LCR provides a food-rich environment for all ages of fish. This temperature regime is also suitable for completion of life cycles of many invertebrate species, especially insects such as blackflies and midges that are important food items for the Humpback Chub. Furthermore, the high TDS and chloride concentrations, combined with periodic scouring floods, provide a rigorous and arduous environment that otherwise disadvantages predaceous and competing nonnative fish species (Kaeding and Zimmerman 1983).

4.2.3 Adequate and Reliable Food Supply—The following is a summary of the food supply for the population of the lower basin followed by a detailed description:

- Starting in 1963, Glen Canyon Dam altered the flow, temperature, and sediment regimes of the Colorado River through Grand Canyon and transformed fundamental biological processes from a heterotrophic to an autotrophic system;
- The current aquatic community in the Lees Ferry reach (0–25 km below dam) is based on high water clarity and photosynthetic production that supports algal species (*Cladophora* and *Oscillatoria*) and a low diversity of cold-adapted invertebrates species; water clarity, photosynthesis, and invertebrate density decrease with distance downstream and turbidity increases from tributaries;
- Invertebrate drift concentration in the Lees Ferry reach is controlled by discharge and benthic density;
- The strong longitudinal pattern of food-web characteristics correlates with the spatial position of large tributaries and with evidence of intense fish competition for food with distance downstream from the dam;
- Food supply in the LCR is seasonally limited, but is in greatest abundance in April and May;
- Humpback Chub are piscivorous and cannibalistic at high density in the LCR; and
- The aquatic food base in Grand Canyon is affected by temperature, daily flow variation, and fish competition, all of which may limit the size of the Humpback Chub population.

There are few published reports on the pre-dam primary biological characteristics of the Colorado River through the Grand Canyon. Woodbury (1959) reported that the river through Glen Canyon was turbid much of the year from torrential floods, but was nearly clear during late summer low flows, suggesting that river productivity was primarily heterotrophic, but that some autotrophic photosynthesis was possible. Most of the pre-dam surveys of algae, diatoms, and invertebrates were species identification lists from tributaries, with no measure of standing biomass from the mainstem. The only study from the Colorado River System was before and after closure of Flaming Gorge Dam on the Green River of the upper basin (Pearson 1967); a river reach that is located at higher elevation than Glen Canyon Dam, and where allochthonous input is not as great and species composition is different.

A better assessment of the pre-dam condition can be gleaned from a study by Haden et al. (2003) of the benthic community structure of Cataract Canyon and the Green and Colorado rivers upstream of Lake Powell; this study provides a contemporary assessment that possibly reflects historical conditions in Grand Canyon. It shows that terrestrial organic matter is the primary energy source for aquatic invertebrates because high levels of suspended sediment inhibit algae growth. The invertebrate community is dominated by filter feeders (blackflies and caddisflies) and collectors (mayflies and midges), reflecting the importance of terrestrial organic matter. Prior to the closure of Glen Canyon Dam, the Colorado River contained large quantities of coarse woody debris (whole trees and branches) and other terrestrial plant material that was transported by landscape floods. This material accumulated in eddies and as huge driftwood piles along the river banks and supported an abundance of terrestrial insects that were also an important food source for fish in the Colorado River (Valdez and Carothers, 1998; Webb et al. 2002).

Numerous post-dam studies of the biological characteristics of the primary and secondary producer community of the Colorado River through Grand Canyon have been conducted and are summarized by Blinn and Cole (1991) and Kennedy and Gloss (2005). Generally, aquatic invertebrate diversity (the number of different species) declined following closure of Glen Canyon Dam, while invertebrate density and biomass increased in the Lees Ferry reach (Blinn and Cole 1991).

These studies describe the fundamental biological processes that were dramatically altered with the construction and operation of Glen Canyon Dam starting in 1963. The dam controls the flow of the river and releases cold water from the lowest layer of Lake Powell, and all sediment and organic matter being carried by the river settle in the reservoir. The altered flow regime, cold water temperature, and increased water clarity have transformed the biological processes of the river from a heterotrophic system, largely dependent on allochthonous carbon sources, to an autotrophic system with a high level of photosynthetic production and autochthonous carbon sources (Shannon et al. 1994; Kennedy and Gloss 2005; Vernieu et al. 2005).

These photosynthetic processes are reduced longitudinally downstream with increasing sediment brought in primarily by large tributaries. Stevens et al. (1997) found that *Cladophora* was the dominant algae from the dam to Lees Ferry with an average mass of 15.5 g C/m^2. Downstream of the Paria River, *Cladophora* standing mass decreased abruptly to 0.5 g C/m^2, and remained low to Diamond Creek. *Oscillatoria* spp., a mat-forming algae, dominated aquatic habitats downstream of Lees Ferry with average biomass of 0.6 g C/m^2 immediately downstream of the Paria River.

The species composition and biomass of aquatic invertebrates also varied with distance downstream during 1991. Stevens et al. (1997) found that the amphipod *Gammarus lacustris* and midges (Chironomidae) were the dominant aquatic invertebrates upstream of the Lees

Ferry reach, whereas, blackflies (Simulidae) were dominant downstream of the Paria River. They also found that invertebrate biomass declined in a downstream direction, with mean biomass of 2.9 g C/m^2 upstream of Lees Ferry and <0.1 g C/m^2 downstream. Hence, even though the Lees Ferry reach accounted for only ~7% of the aquatic habitat in the 390 km of river, it supported ~64% of the primary producer biomass and 87% of the invertebrate biomass. This downstream decline in productivity was attributed to decreased water clarity from tributary sediment input and to cold water temperature that precludes historical invertebrate species from becoming established.

Kennedy et al. (2013) showed that invertebrate drift concentrations in the Lees Ferry reach were jointly controlled by discharge and benthic densities operating at different timescales. They showed that a 2-fold variation in discharge associated with hydropeaking resulted in a >10-fold increase in drift concentration of benthic invertebrates associated with pools and detritus (i.e. *Gammarus lacustris* and New Zealand mudsnails). Conversely, drift concentration of sessile blackfly larvae that are associated with high-velocity cobble habitats, decreased by over 80% as discharge doubled, and was positively related to benthic density. This demonstrated that the propensity for insect taxa to drift and for non-insect taxa to avoid drifting probably underlies the structural changes in the invertebrate assemblage of the Colorado River after dam construction.

Dodrill et al. (2016) also found large differences in genus-level invertebrate richness for three western U.S. rivers. The Green River below Fontenelle Dam had a low hydropeaking index and the invertebrate assemblage was comprised of 54 unique genera, including many insects. The Green River below Flaming Gorge Dam had a moderate hydropeaking index and contained 47 unique genera; whereas the Colorado River below Glen Canyon Dam had a high hydropeaking index and supported only 12 unique genera, most of which are non-insects. Dodrill et al. (2016) found a virtual absence of EPT species (mayflies [E], stoneflies [P], and caddisflies [T]) in the Colorado River downstream of Glen Canyon, and suggested that hourly discharge variation from hydropeaking operations limits the success of aquatic egg-laying insect species whose eggs are desiccated during the incubation cycle.

Notably, several species of cold-tolerant nonnative invertebrates were intentionally introduced into the Colorado River after Glen Canyon Dam was closed in 1963. Altogether 10,000 immature mayflies were secured from a commercial source in Minnesota and released at three sites in the Lees Ferry reach. Also, 10,000 snails, 5,000 leeches, and thousands of insects representing at least 10 families were transported from the San Juan River in New Mexico to the river near Lees Ferry. In addition, 50,000 "scuds" (*Gammarus lacustris*) were introduced into Bright Angel Creek in 1932 and at Lees Ferry and below the dam in 1968, in addition to 2,000 crayfish taken from the LCR near Springerville, AZ (Blinn and Cole 1991). *Gammarus lacustris* has thrived in the cold, clear reaches below the dam, but the fate of the other introduced species is unknown.

Other nonnative invertebrate species have been found recently in the Grand Canyon, probably from incidental natural or human introductions, including the New Zealand mudsnail (*Potamopyrgus antipodarum*) and the red swamp crayfish (*Procambarus clarkii*). The quagga mussel (*Dreissena bugensis*) and Asiatic clam (*Corbicula* spp.) are abundant in Lake Powell and Lake Mead. Habitat in the Grand Canyon is unsuitable for the Asiatic clam, and is marginally suitable for the quagga mussel (Kennedy 2007), which has been found as one adult at RM 209 in April, 2015 (NPS unpublished data), and one adult near RM 60 (upstream of LCR confluence) in 2017 (USGS unpublished data).

Humpback Chub in the Colorado River through the Grand Canyon are typically omnivores, with a diet consisting of insects, crustaceans, plants, seeds, and occasionally small fish and reptiles (Valdez and Ryel 1995). Adults fed heavily on floating material entrained in eddies and low-velocity areas during an artificial flood in Grand Canyon, and the fish often feed on sporadic food supplies during large floods (Valdez and Hoffnagle 1999).

There is a strong longitudinal pattern in food-web characteristics that correlates with the spatial position of large tributaries, with evidence of intense competition for food with distance downstream from Glen Canyon Dam (Cross et al. 2013). Food supply in the LCR appears to be seasonally limited with greatest abundance in April and May; declining food supply after May could contribute to the age-0 fish descending from the LCR to the mainstem. During high densities in the LCR, the Humpback Chub is known to be cannibalistic, but the magnitude of piscivorous activity is unknown (Stone and Gorman 2006). Also, although Humpback Chub are omnivorous and may consume small fish on occasion, Spurgeon et al. (2015) found that translocated Humpback Chub in Shinumo Creek consumed fish as a large part of their diet.

Hayes et al. (2017) found that the juvenile Humpback Chub length–weight relationship during the warm-water period in 2011 did not differ from the relationship seen in the 1990s. In fact, at the larger fish sizes (> 150 mm TL), the predicted weight for a given length was lower in 2011 compared with several years in the early 1990s. These results were corroborated by Dodrill et al. (2014), who documented that Humpback Chub grew slower in 2011, despite the warmer water temperatures. This counterintuitive response indicates that Humpback Chub in Grand Canyon may be food-limited, even if optimal temperatures and more natural flows are experimentally provided.

4.2.4 Habitat With Few Nonnative Predators and Competitors—The following is a summary of predators and competitors in the population of the lower basin followed by a detailed description:

- ~50 species of nonnative fish have been introduced into the lower basin in the last 100 years; of 24 species that have been reported in the Grand Canyon, 13 are considered principal predators and competitors;

- Principal predators of juvenile Humpback Chub in the LCR include Channel Catfish and Black Bullhead, and predators in the mainstem are primarily Rainbow Trout and Brown Trout;
- In the LCR, competition for sub-adult Humpback Chub is primarily over food and space with Channel Catfish, Common Carp, and Black Bullhead, as well native Flannelmouth Sucker and Bluehead Sucker; competition in the mainstem is primarily with Rainbow Trout over food, as there is a strong longitudinal pattern in food-web characteristics that correlates with spatial position of large tributaries;
- New species (e.g., Smallmouth Bass) and expansions of existing nonnative species (e.g., Green Sunfish, Brown Trout) continue to raise concerns over warmer dam releases and the potential for increases of these populations; and
- Nonnative fish management is ongoing in the Grand Canyon to reduce the impact of nonnative predators and competitors.

Nearly 70 species of nonnative fish have been introduced into the Colorado River System in the last 100 years, including ~50 in the lower basin. Lists and descriptions of these fishes can be found in Minckley (1991), Minckley and Deacon (1991), Valdez and Ryel (1995), and Pacey and Marsh (1998). Predation is a major threat to the Humpback Chub in the Grand Canyon—as in the upper basin. ~24 species of nonnative fishes commonly occupy habitat used by the Humpback Chub in Grand Canyon, with 13 considered the principal predators and competitors (Figure 25).

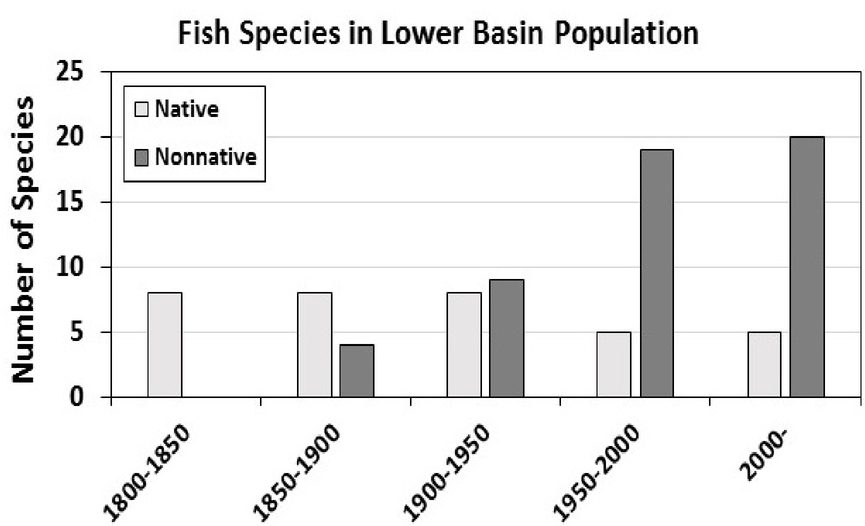

Figure 25. Numbers of native and nonnative fish species in the Humpback Chub population of the Grand Canyon.

Principal predators of juvenile Humpback Chub in the LCR include Channel Catfish and Black Bullhead (Marsh and Douglas 1997), and predators in the mainstem are primarily Rainbow Trout and Brown Trout (Yard et al. 2011). Valdez and Ryel (1995) surmised that predation by Rainbow Trout and Brown Trout in the mainstem could lead to a complete loss of Humpback Chub year classes during cold dam releases, and Petersen and Paukert 2005 concluded that the window of vulnerability to predation in the mainstem would be shorter if warmer water temperature generated higher growth rates for juvenile Humpback Chub. Yard et al. (2011) determined that the incidence of predation by Brown Trout was higher (8–70%) than by Rainbow Trout (0.5–3.3%), but because the latter species is 50 times more abundant and consumes more fish (65% by Rainbow Trout and 35% by Brown Trout), the Rainbow Trout was considered the more significant predator. They also determined that Rainbow Trout and Brown Trout ingested 85% more native fish than nonnative fish despite native fish comprising less than 30% of small fish numbers.

Competition is also a threat from nonnative fish. In the LCR, competition for sub-adult Humpback Chub is primarily over food and space with Channel Catfish, Common Carp, and Black Bullhead, as well as native Flannelmouth Sucker, Speckled Dace, and Bluehead Sucker (Marsh and Douglas 1997). In the mainstem, competition is primarily with Rainbow Trout over food, as there is a strong longitudinal pattern in food-web characteristics that correlate with the spatial position of large tributaries (Cross et al. 2013). Invertebrate production declines ~18-fold below large tributaries while fish production remains similar to upstream sites and is predominately native fish taxa (80–100% of production). Many nonnative fish species occupy the same habitat as Humpback Chub in the Grand Canyon. These fish could increase in abundance with warmer dam releases, but of particular concern are highly predaceous species like Smallmouth Bass, Walleye, Channel Catfish, Green Sunfish, and Red Shiner. Actions to control the numbers of nonnative fish and to prevent expansion of invading species are ongoing and part of fish management in the Grand Canyon (see section 4.4).

4.2.5 Suitable Water Quality—The following is a summary of water quality in the population of the lower basin followed by a detailed description:

- Spring runoff in the LCR can transport a variety of municipal, agricultural, and industrial pollutants from the landscape that could detrimentally affect the principal spawning area of Humpback Chub in the Grand Canyon;
- The Arizona Department of Transportation completed a project in fall 2016 to replace the bridge at Cameron, AZ, substantially reducing the threat of accidental vehicle collisions and spills into the LCR that could reach critical habitat;
- Regional drought has led to a greater incidence of range fires and subsequent ash and debris-laden floods, such as those that killed and displaced a translocated group of Humpback Chub in Shinumo Creek in July and August 2014; and
- Water quality is not known to be limiting the Humpback Chub population in the Grand Canyon.

Water Quality and Contaminants—Water quality of the Colorado River through the Grand Canyon is determined largely by the water being released through Glen Canyon Dam and by tributary floods. No specific toxic materials or contaminants have been identified with detrimental effects to the Humpback Chub population. The cold stenothermic temperature has been identified as limiting mainstem life stages of warm-water native fishes, and changes in food-web dynamics in the Grand Canyon have been attributed to a reduction in nutrients that are largely retained in Lake Powell (Vernieu et al. 2005).

The biggest threat from water quality to Humpback Chub in the Grand Canyon is materials being washed from the landscape and down the LCR, where the majority of spawning takes place. The LCR has a base flow of ~237 cfs that originates from the Blue Springs complex ~20 km upstream from the mouth. Spring runoff in the LCR comes from a high elevation desert landscape with scattered towns and villages (ADWR 2009a) which can contain a variety of municipal, agricultural, and industrial pollutants. These contaminants tend to not reside long in the LCR and are flushed through and diluted in the mainstem Colorado River. There is no known detrimental effect of this seasonal flush of contaminants through the system.

Catastrophic Spills—Another major threat to water quality in the LCR is the possibility of an accidental spill of materials from an overturned truck at the U.S. Highway 89 Bridge at Cameron, AZ. This bridge is ~60 km upstream of designated critical habitat occupied by the Humpback Chub in the LCR. During much of the summer, the LCR is dry at Cameron, but substantial floods in spring and fall could quickly transport spilled material to habitat being used by spawning fish. Such a spill has never occurred, and fortunately, this threat has been reduced with replacement of the 58-year old 2-lane bridge with a 4-lane bridge by the Arizona Department of Transportation in fall 2016.[8] The project also constructed a roundabout at the intersection of US 89 and SR 64 to slow traffic in the Cameron area and to facilitate the flow of traffic. This construction should reduce the threat of accidental vehicle collisions and spills of materials into the LCR and substantially lessen this threat to the Humpback Chub.

Inflow of contaminants can also occur during a natural episodic event. Large floods and a large debris flow in Shinumo Creek in July and August 2014 killed or displaced a translocated population of Humpback Chub (Healy et al. 2014c). The physical scouring of the event and a dramatic geomorphic change in habitat, combined with a large volume of ash from a recent fire in the watershed, were probably the principal factors that eliminated most fish from the system, including Humpback Chub, Bluehead Sucker, Rainbow Trout, and Speckled Dace; a few Speckled Dace remained after the debris flow in isolated pockets. These floods entered the mainstem Colorado River where a large amount of debris and ash was reported, but with no detrimental effects (Emily Omana-Smith, National Park Service, Personal Communication, August, 2016).

[8] see: http://azdot.gov/projects/ north-central/us-89-cameron-roadway-improvements/overview

Water quality is not known to be limiting the Humpback Chub population in the Grand Canyon. Most water quality parameters are monitored in Lake Powell, through Grand Canyon, and in Lake Mead, and notable changes in a contaminant should be detected.

4.2.6 Unimpeded Range and Connectivity—The following is a summary of connectivity in the population of the lower basin followed by a detailed description:

- The population in Grand Canyon consists of a core population in and near the LCR and fish in the mainstem, including six aggregations located 41–90 km apart;
- There is no mainstem impediment to movement between Glen Canyon Dam and Hoover Dam; but there are chutes or small falls that impede movement ~14 km up the LCR, and in lower Shinumo Creek and Havasu Creek; Humpback Chub have been translocated above these barriers;
- Habitat appears to be expanding in western Grand Canyon with the receding level of Lake Mead and the ongoing carving of deltaic deposits in the lake inflow; these are exposing the original rock channel and enabling the species to reoccupy historical habitat;
- The Grand Canyon population is connected by movements of fish that augment existing aggregations and may populate unoccupied intervening areas; this movement is sufficient for genetic exchange, but the demographic effect is unclear; and
- At a species level, Glen Canyon Dam is a barrier to movement between the upper and lower basins.

The population of Humpback Chub in the Grand Canyon consists of a core population in and near the LCR and six aggregations located 124 to 368 km downstream of Glen Canyon Dam (Valdez and Ryel 1995; Persons et al. 2015). This population has been isolated from the five upper basin populations by the dam since 1963. The six aggregations are spaced 41, 69, 28, 43, and 90 km apart, with some movement of fish among aggregations and some fish occupying intervening areas.

The habitat of the Humpback Chub appears to be expanding in western Grand Canyon with the receding level of Lake Mead and the ongoing carving of deltaic deposits in the lake inflow, exposing the original rock channel and habitat historically occupied by the species (Bookstein et al. 1985). Surveys of western Grand Canyon (Diamond Creek to Pearce Ferry, RM 225-280), when the area was inundated by Lake Mead (Valdez 1992, 1994; Valdez et al. 1995), and as the river channel was being exposed by receding lake levels (Van Haverbeke et al. 2007), yielded fewer than 10 Humpback Chub. Recent small-fish sampling downstream of Lava Falls Rapid (RM 180) to Pearce Ferry (in the newly exposed river channel) yielded 18 and 67 larvae in 2014 and 2015, respectively (Albrecht et al. 2015; Kegerries et al. 2016).

Sampling by the Arizona Game and Fish Department (AGFD) with electrofishing (since 2000) and hoop nets (since 2016) has revealed densities of Humpback Chub in this lower reach comparable to and greater than areas traditionally considered aggregations (Rogowski et al. 2017). All age and size classes of Humpback Chub were represented below Diamond Creek with hoop nets in 2016, demonstrating that reproduction and recruitment occur in this reach. Only two of 145 fish captured below Diamond Creek were recaptures; whereas 50–80% of Humpback Chub in aggregations are recaptures (Persons et al. 2015). These tagging results indicate that Humpback Chub captured below Diamond Creek did not originate from the LCR or any of the identified aggregations, but are from local reproduction and recruitment. The presence of Humpback Chub and evidence of successful recruitment in western Grand Canyon has important implications as an extension of the core population, or possibly as a second reproducing population in the Grand Canyon.

Although most movement by Humpback Chub in the Grand Canyon is adults moving from the mainstem to spawn in the lower LCR (Yackulic et al. 2014), some fish move greater distances. Paukert et al. (2006) reported that two fish moved 52 km to and from the mainstem and the LCR within 1 year, and five fish moved 154 km to and from Havasu Creek and the LCR in a period of 2 to 5 years. Most extended movements are in a downstream direction with fish originating primarily in the LCR and moving to downstream mainstem aggregations (Valdez and Ryel 1995; Coggins 2008). This indicates that the Grand Canyon population is connected by movements of fish that augment existing aggregations, and this movement may serve to populate unoccupied habitats. The movement of individuals is certainly sufficient for genetic exchange, but the demographic effect is unclear.

Historically, Chute Falls (14.1 km up the LCR) was considered an impassible barrier to all upstream movement of Humpback Chub (Kaeding and Zimmerman 1983; Mattes 1993; Robinson et al. 1996). In 2007, 2009, and 2016, six Humpback Chub tagged below the falls were recaptured above the falls, confirming that at least small numbers of fish are able to move upstream to the area of the Blue Spring complex (Stone 2016). The Blue Springs complex, which is located ~20 km up the LCR is a chemical barrier to fish because of high carbon dioxide levels in the immediate vicinity of the springs (see section 4.2.2).

A steep chute falls at the mouth of Shinumo Creek blocks upstream movement of fish into that tributary, except at very high flows not currently seen in the Grand Canyon. A series of smaller chutes in lower Havasu Creek also impede fish movement into that tributary, except at high dam releases, such as during equalization flows and high-flow experiments. Juvenile Humpback Chub have been translocated from the LCR to each of these tributaries (see section 4.5.6), and the fish are currently showing signs of reproduction in Havasu Creek, but the fish were unfortunately killed or displaced by a series of large ash and debris-laden floods in Shinumo Creek.

4.2.7 ***Persistent populations***—The following is a summary of the population in the lower basin followed by a detailed description (see section 4.5 for the demographic status of each population):

- The only population of Humpback Chub in the lower basin is in the Colorado River in Marble and Grand canyons, as well as the lower LCR and Havasu Creek;
- Since population estimates began in 1989, the number of adults in the LCR core population decreased by 54% from 10,946 in 1989 to 5,021 in 2001, and then increased by 52% from 5,021 to 7,650 in 2008; subsequent estimates using an alternative method that is not directly comparable are ~12,000 adults in 2012 (more recent estimates are not available); abundance estimates appear stable since 2009 (C. Yackulic, personal communication, 2017);
- There is evidence of successful spawning in Havasu Creek and at two additional mainstem locations (RM 30, RM 214);
- In addition to the core population in and near the LCR, ~250 adults and several hundred juveniles and sub-adults are distributed in ~408 km of the mainstem, with evidence of reproduction in western Grand Canyon; and
- The population of Humpback Chub in the Grand Canyon has undergone large changes, but is persistent as a core population with several mainstem aggregations and evidence of expansion in abundance and distribution.

The only population of Humpback Chub in the lower basin is in Marble and Grand canyons, with individuals occupying ~400 km of the mainstem Colorado River from RM 30 to RM 280, as well as ~18 km of the lower LCR and ~6 km of lower Havasu Creek. The core population (LCR population) includes fish from the LCR and fish in an area of ~15 km of the mainstem around the LCR confluence that move annually into the LCR to spawn and mix with resident fish (Kaeding and Zimmerman 1983; Valdez and Ryel 1995; Douglas and Marsh 1996). Most adults return to the mainstem after spawning, although some remain in the LCR for various periods of time (Yackulic et al. 2014).

Since population estimates began in 1989, the number of adults in the LCR core population decreased by 54% from 10,946 in 1989 to 5,021 in 2001, and then increased by 52% from 5,021 to 7,650 in 2008 (Coggins and Walters 2009). The average of 20 estimates for 1989–2008 is 7,080 adults. More recent estimates of adult abundance for 2009–2012 show a stable population of ~11,500–12,000 adults (Appendix S3 of Yackulic et al. 2014), and were developed using an alternative method that is not directly comparable to previous estimates.

In addition to the fish in and near the LCR, ~250 adults and several hundred juveniles and sub-adults occur in six mainstem aggregations distributed in ~295 km of the mainstem from RM 30 to RM 213 (Valdez and Ryel 1995); the numbers of individuals in these aggregations have been increasing since ~2014 (Persons et al. 2015). In 2015 and 2016, fish of all ages were also found in western Grand Canyon as far downstream as Pearce Ferry (RM 280;

Kegerries et al. 2016; Rogowski et al. 2017), which extends the current distribution of the species in Grand Canyon by ~108 km (67 mi).

Small numbers of fish move among the various mainstem aggregations (Paukert et al. 2006; Persons et al. 2015), and dispersal from the LCR may account for the fish in the lower canyon; however, spawning may be taking place in the lower canyon or in downstream tributaries, such as Havasu Creek (Nelson et al. 2016). Also, in 2014 a cohort of age-0 was detected near RM 214 (Pumpkin Springs aggregation), which could be followed into the age 1 and sub-adult size class during sampling in 2015 and 2016, respectively. Since 2014, ~345 Humpback Chub have been captured in hoopnets between Pumpkin Springs and Surprise Canyon, consisting of all size classes, and more juvenile Humpback Chub were captured with seines (Randy VanHaverbeke, U.S. Fish and Wildlife Service, Personal Communication, January 20, 2017).

4.2.8 High Genetic Diversity—The following is a summary of the genetic diversity of the population in the lower basin followed by a detailed description:

- Humpback Chub in the Grand Canyon are connected by gene flow with movement of fish within the mainstem and between the LCR and mainstem;
- Hybridization is not occurring in the Grand Canyon population because the Humpback Chub is the only *Gila* species remaining in the mainstem and lower end of tributaries;
- For a current population estimate of 9,000 to 12,000 adults associated with the LCR, genetic effective population is 899–1,437 adults; and
- A genetic analysis of fish from the LCR shows that the fish are genetically diverse with low and non-significant inbreeding coefficients, high levels of observed heterozygosity, and high allelic diversity.

The aggregations of Humpback Chub in the Grand Canyon are connected by gene flow with movement of fish among the LCR population and six aggregations. Surveys since the year 2000 (Rogowski et al. 2017) have revealed large numbers of Humpback Chub in western Grand Canyon (below Diamond Creek), but with few recaptured individuals, suggesting successful local reproduction. Neither Roundtail Chub nor Bonytail are present in areas occupied by the Grand Canyon population, and hybridization is not occurring. However, L msat analysis indicates evidence of historical hybridization with Bonytail haplotypes present in the 30-mile Marble Canyon aggregation (Douglas and Douglas 2007).

Genetic evidence of historical hybridization in the Grand Canyon is supported by collections of the three *Gila* species. In the 1940's, 5 Humpback Chub were collected from western Grand Canyon (at Lava Falls Rapid near Spencer Creek) along with 16 Bonytail and 6 Roundtail Chub (Miller 1944; Bookstein et al. 1985), indicating that the three species were historically sympatric in the Grand Canyon. The Roundtail Chub was common in the Glen

Canyon Dam tailwaters in 1967–1968, following dam closure (Stone and Rathbun 1968), but was probably locally extirpated by the cold dam releases and dramatic changes to the river ecosystem. The species is currently present in two tributaries of the upper LCR (Chevelon and East Clear creeks), but no individuals have been documented in the lower LCR or in the Grand Canyon since the 1960s.

The U.S. Fish and Wildlife Service has established a refuge population of ~1,000 adult Humpback Chub from the LCR at the Southwestern Native Aquatic Resources and Recovery Center (SNARRC) in Dexter, New Mexico. A genetic analysis of these fish shows that the fish are genetically diverse with low and non-significant inbreeding coefficients, high levels of observed heterozygosity, and high allelic diversity (Wilson 2014). A single sample estimate of the effective number of breeders (N_b, or the number of breeders in a single time period of one year) varied from 143 to 203, indicating the range in number of individuals that successfully spawn in the LCR each year. The effective population size (N_e) is a harmonic mean of 1,437 at a survival rate (S) of 0.87, and 899 at S of 0.82. This is the effective size of the population that contributes genetic information to the next generation and influences long-term genetic drift and evolutionary potential.

For a current population estimate of 9,000–12,000 adults associated with the LCR and an S of 0.87, the N_e/N_c is 0.12–0.16, whereas the N_e/N_c when S is 0.82 is 0.08–0.10 (Wilson 2014). Hence, at a higher survival rate of 0.87, between 12% and 16% of the adult population contribute genetic information to the next generation, and although the estimated LCR census size (N_c) is 9,000–12,000 adults, the effective population is comparable to a population of 899–1,437 adults, in terms of genetic drift (loss of allelic diversity), mutation (creation of new genetic diversity), and overall evolutionary potential. This appears to be a small proportion of the population and may be explained by low egg survival from rigorous water quality conditions in the LCR (see section 4.2.2) or by skipped spawning.

4.3 Current Condition of Species Needs by Population

The following is a summary of the current condition of species needs within each of the six Humpback Chub populations (Table 7):

1. **Black Rocks:** The physical habitat, temperature, food supply, and connectivity are in good condition. The population is small but dense (~400 Humpback chub / mile) persistent. Flows are altered, but are being managed and have improved since 1999 (date of the 15 Mile Reach PBO), and water quality does not appear to be detrimental. Removal of nonnative Smallmouth Bass, Walleye, Channel Catfish, Largemouth Bass in Black Rocks and adjacent areas upstream and downstream help to maintain low numbers of nonnatives (see section 4.1.4 and 4.4); despite occasional short-term increases in Largemouth and Smallmouth Bass densities within and near to Black Rocks, densities typically return to low levels within a few years. The most abundant species overall is the Roundtail Chub (44% to total numbers) that hybridizes and

competes with the Humpback Chub. Although genetic diversity is high in this population, introgressive hybridization is relatively high (Bohn and Wilson 2017) as Roundtail Chub move into this area in years of low spring flow (Francis et al. 2016). Despite periodic increases in nonnative fish densities, the large abundance of Roundtail Chub, and the small geographic scope of the habitat, Humpback Chub have persisted at this location since major changes (flow alteration and establishment of Channel Catfish) occurred more than 50 years ago.

2. **Westwater Canyon:** The condition of resources in Westwater Canyon is similar to the condition of nearby Black Rocks, including a similar composition of nonnative fish, primarily Channel Catfish, has remained static for more than 50 years. Despite occasional short-term increases in Largemouth and Smallmouth Bass densities within and near to Westwater Canyon, densities typically return to low levels within a few years. Control of nonnative fishes within Westwater Canyon, as well as areas upstream and downstream, also help to keep numbers low. The biggest difference between these proximate populations is that Westwater Canyon supports lower numbers of Roundtail Chub (26.5% in Westwater and 44% in Black Rocks). Evidence of hybridization is present in Westwater Canyon, and expansion of Roundtail Chub into this area also appears to be higher in years of low spring flow.

3. **Desolation/Gray canyons:** Desolation/Gray canyons are on the Green River, but resource conditions are similar for this population as for Black Rocks and Westwater Canyon on the Colorado River. Peak and base flows have improved since implementation of Muth et al. 2000, via Bureau of Reclamation Record of Decision in 2006. However, unlike populations on the Colorado River (Black Rocks, and Westwater and Cataract Canyons), the nonnative fish assemblage has changed in the past decade; a recent range expansion of Smallmouth Bass is concerning. Densities of Walleye and large Channel Catfish are low and Northern Pike are largely absent from this reach, but densities of Smallmouth Bass can reach elevated levels when upstream production is high. Smallmouth bass densities return to lower levels upon reduction of upstream production because of limited recruitment in the local area, but the species has apparently increased its established range with the canyon. Nonnative fish removal occurs within Desolation/Gray canyons, as well as areas upstream and downstream to keep the numbers of nonnative fish low. The Desolation/Gray canyons area has been subject to ash flows following range fires and to petroleum spills; these catastrophic events have been particularly stressful to the population as they often occur during low summer flows when water temperature is high and the river volume is low for dilution of contaminants.

4. **Cataract Canyon:** Resource conditions in Cataract Canyon appear to be good to moderate, as indicated for the three previously described populations. Flow management since 1999 on the Colorado River mainstem and since 2006 on the Green River have improved inter- and intra-annual flow variability, which we suspect improves conditions for Humpback Chub. Cataract Canyon is located downstream of

the confluence of the Colorado and Green rivers where high combined flows, arduous whitewater rapids, and few backwaters and sheltered habitats tend to reduce overall fish numbers. Nonnative fish in Cataract Canyon are dominated by Channel Catfish, Common Carp, Black Bullhead, Red Shiner, and Fathead Minnow, but this community composition has remained largely unchanged for many decades and Humpback Chub have persisted. Captures of Smallmouth Bass, Walleye, and Northern Pike within Cataract Canyon are very rare. The population of Humpback Chub in Cataract Canyon is small but persistent with probably fewer than 300 adults. The small size of this population raises concern over susceptibility to nonnative fishes moving up from Lake Powell and to long-term viability.

5. **Dinosaur National Monument:** Few Humpback Chub remain in the DNM population that includes the Yampa and Whirlpool Canyons. This population declined upon completion of Flaming Gorge Dam in the 1960s and has been tenuous since. The population is now considered functionally extirpated because Humpback Chub have not been collected in the Yampa River since 2004 (Finney 2006) and in the Green River since 2006 (Bestgen & Irving 2006).

   Population viability has been negatively impacted from multiple stressors, such as rotenone treatment in the Green River in 1962 (Holden 1991), cold hypolimnetic releases from Flaming Gorge Dam after 1963 (Holden and Crist 1981), expansion of nonnative fish (Haines et al. 2006), and exceptionally low Yampa River flows in the early 2000s. Dam penstock modifications in 1978 warmed releases and native fish have reinvaded historic habitat in the Green River above the Yampa River confluence, but not the Humpback Chub (Bestgen et al. 2006). Influxes of Smallmouth Bass occur when nearby production is high, but densities return to lower levels as nearby production is reduced. The habitat in DNM is otherwise suitable for Humpback Chub, but the number of fish is so low that intervention (e.g., fish translocation or stocking) will be necessary to restore this population.

   Native fish communities remain strong in both Yampa and Whirlpool canyons despite large densities of nonnative fish in nearby reaches, but lack Humpback Chub. The altered thermal regime in the Green River upstream of the confluence with the Yampa River precludes Humpback and Roundtail Chub from occupying this reach. Humpback Chub residing in DNM are therefore more reliant on Yampa Canyon and the natural thermal regime found there. However, summer base flows in Yampa Canyon are an order of magnitude lower than any other Upper Basin locations where Humpback Chub are found. Furthermore, in the early 2000's Yampa Canyon experienced brief periods of no surface flow. Since 2007, the UCRRP has augmented summer low flows in Yampa Canyon with a permanent pool (5,000 ac-ft) of fish water available in Elkhead Reservoir. The success of reestablishing a population of Humpback Chub in DNM will be dependent on the presence of adequate flow conditions.

6. **Grand Canyon:** Although the resources for this population have been altered by the construction and operation of Glen Canyon Dam, ongoing management is helping to maintain suitable habitat for the Humpback Chub and the species has shown a great deal of adaptability to a wide range of flow and temperature. The proportion of nonnative fish in Grand Canyon is among the lowest of the six populations (27%) and ongoing management actions help to prevent expansion of invading nonnative fish species (see section 4.2.4). The population increased from minimum levels observed in the early to mid-2000s and has been stable since 2008. The population appears to be continuing to expand in numbers and distribution in the mainstem into western Grand Canyon and from translocations to Havasu Creek and the LCR.

This assessment shows that species needs are generally in fair to poor condition for the six populations of Humpback Chub, and specific resources need ongoing management (river flow and nonnative fish, along with temperature and aquatic foodbase in the Grand Canyon). One population, DNM, will need intervention (translocation or stocking of fish) to restore the population.

River flow and predation/competition are the key factors controlling upper basin populations of Humpback Chub; whereas, river flow, water temperature, food supply, and predation/competition are the key factors controlling the lower basin population.

Table 7. A summary of the current condition of species needs for the six populations of the Humpback Chub. Color codes: dark green = resource condition is good; light green = resource condition is fair; yellow = resource condition is neutral; orange = resource condition is fair; red = resource condition is bad.

Resource Category	Black Rocks	Westwater Canyon	Desolation/Gray canyons	Cataract Canyon	Dinosaur National Monument	Grand Canyon
1. Diverse rocky canyon river habitat	**Good** • Occupies 1.4 km of upper Colorado River on or adjacent to land managed by Bureau of Land Management and state of Colorado. • Regulations control access and use by rafters. • Some mining activity in area, but does not affect river channel. • Some encroachment by nonnative tamarisk but immeasurable effect to habitat. • Physical habitat intact.	**Good** • Occupies 13.5 km of upper Colorado River on or adjacent to land managed by Bureau of Land Management and state of Utah. • Regulations control access and use by rafters. • Some encroachment by nonnative tamarisk but immeasurable effect to habitat. • Physical habitat intact.	**Fair** • Occupies 75.8 km of Green River on or adjacent to land managed by Bureau of Land Management, Ute Tribe, and state of Utah. • Regulations control access and use by rafters. • Some encroachment by nonnative tamarisk but immeasurable effect to habitat. • Physical habitat intact.	**Fair** • Occupies 25.6 km of upper Colorado River on or adjacent to land managed by Canyonlands National Park and state of Utah. • Regulations control access and use by rafters. • Some encroachment by nonnative tamarisk but immeasurable effect to habitat. • Physical habitat intact.	**Fair** • Occupies 52.1 km of Yampa River and previously in 45.1 km of the Green River on or adjacent to land managed by Dinosaur National Monument and states of Colorado and Utah. • Regulations control access and use by rafters. • Some encroachment by nonnative tamarisk but immeasurable effect to habitat. • Physical habitat intact.	**Good** • Occupies 405.5 km of Colorado River, lower 18 km of the Little Colorado River, and lower 5.6 km of Havasu Creek on or adjacent to lands managed by Glen Canyon National Recreation Area and Grand Canyon National Park, state of Arizona, Navajo Nation, Hopi Tribe, Hualapai Tribe, and Havasupai Tribe. • Regulations control access and use by rafters. • Encroachment by nonnative tamarisk in backwaters used by small numbers of native fish. • Physical habitat intact, except sediment managed by flow.
2a. Suitable flow	**Neutral/Ongoing Management** • Spring flow reduced by 33%, base flow increased by 37% since 1964. • Flow management since 2000 has restored important intra- and inter-annual variability. • Little additional flow alteration in last 20 years, but recent and ongoing drought has contributed to flow reduction.	**Neutral/Ongoing Management** • Spring flow reduced by 33%, base flow increased by 37% since 1964. • Flow management since 2000 has restored important intra- and inter-annual variability. • Little additional flow alteration in last 20 years, but recent and ongoing drought has contributed to flow reduction.	**Neutral/Ongoing Management** • Spring flow reduced by 34%, base flow increased by 76% since 1964. • Flow management since 2006 has restored important intra- and inter-annual variability. • Little additional flow alteration in last 20 years, but recent and ongoing drought has contributed to flow reduction.	**Neutral/Ongoing Management** • Spring flow reduced by 33-34%, base flow increased by 37–76% since 1964. • Flow management in Green (since 2006) and Colorado (since 2000) rivers has restored important intra- and inter-annual variability. • Little additional flow alteration in last 20 years, but recent and ongoing drought has contributed to flow reduction.	**Neutral/Ongoing Management** • Little flow regulation in Yampa River; flow regulated in Green River by Flaming Gorge Dam. • Since 2007, 5,000 ac-ft fish pool (with an option for an additional 2,000 ac-ft) available to augment base flows. • Flow reduction from recent and ongoing drought.	**Neutral/Ongoing Management** • Spring flow reduced by 80% and base flow increased by 67% since 1963. • Flow is determined by 2016 LTEMP EIS; Glen Canyon Dam releases designed to minimize impacts on canyon resources.
2b. Suitable temperature	**Fair** • Temperature of the upper Colorado River basin has increased 1.2°C in the 20th century, but effect of warmer water on Humpback Chub has not been measured.	**Fair** • Temperature of the upper Colorado River basin has increased 1.2°C in the 20th century, but effect of warmer water on Humpback Chub has not been measured.	**Fair** • Temperature of the upper Colorado River basin has increased 1.2°C in the 20th century, but effect of warmer water on Humpback Chub has not been measured.	**Fair** • Temperature of the upper Colorado River basin has increased 1.2°C in the 20th century, but effect of warmer water on Humpback Chub has not been measured.	**Fair** • Temperature of the upper Colorado River basin has increased 1.2°C in the 20th century, but effect of warmer water on Humpback Chub has not been measured.	**Fair** • Cold releases from Glen Canyon Dam are largely dependent on dam operations and Lake Powell elevation. • Warmer releases have occurred in fall since 2004 because of low reservoir elevation.

Resource Category	Black Rocks	Westwater Canyon	Desolation/Gray canyons	Cataract Canyon	Dinosaur National Monument	Grand Canyon
3. Adequate and reliable food supply	**Fair** • Food is supplied by instream production of invertebrates, insect emergences, and floods laden with debris. • Food supply has not been measured, but is not believed to be altered.	**Fair** • Food is supplied by instream production of invertebrates, insect emergences, and floods laden with debris. • Food supply has not been measured, but is not believed to be altered.	**Fair** • Food is supplied by instream production of invertebrates, insect emergences, and floods laden with debris. • Food supply has not been measured, but is not believed to be altered.	**Fair** • Food is supplied by instream production of invertebrates, insect emergences, and floods laden with debris. • Food supply has been assessed and is not measurably altered.	**Fair** • Food is supplied by instream production of invertebrates, insect emergences, and floods laden with debris. • Aquatic diversity has been altered.	**Poor** • Aquatic insect diversity is low; productivity has declined, and is affecting fish condition. • Management effectiveness uncertain with studies ongoing to investigate instream production.
4. Habitat with few nonnative predators and competitors	**Fair/Ongoing Management** • 13 principal nonnative predators and competitors that may reduce survival of young and recruitment. • Nearby populations of Smallmouth Bass and Walleye have yet to colonize Black Rocks. • Increased Largemouth Bass catches in 2012 have declined to low numbers.	**Fair/Ongoing Management** • 13 principal nonnative predators and competitors that may reduce survival of young and recruitment. • Nearby populations of Smallmouth Bass and Walleye have yet to colonize Westwater Canyon.	**Neutral/Ongoing Management** • 11 principal nonnative predators and competitors that may reduce survival of young and recruitment. • Smallmouth Bass recently expanded range within the canyon. • Periodic increases in densities of Smallmouth Bass from upstream production, but recruitment is limited.	**Fair/Ongoing Management** • 13 principal nonnative predators and competitors that may reduce survival of young and recruitment. • Possible movement of some predators from Lake Powell through the canyon (e.g., Smallmouth Bass and Walleye) but these species have not colonized Cataract Canyon.	**Neutral/Ongoing Management** • 10 principal nonnative predators and competitors that may reduce survival of young and recruitment. • Periodic increases in densities of Smallmouth Bass from upstream and downstream production, but recruitment is limited. • Upstream production of Northern Pike supplies migrating adults. • Smallmouth Bass and Northern Pike have not colonized canyon habitats	**Neutral/Ongoing Management** • 13 principal nonnative predators and competitors; primary predators are Rainbow Trout and Brown Trout. • Increase of Brown Trout in Lees Ferry reach, causes(s) currently unknown but being investigated.
5. Suitable water quality	**Neutral—Poorly Understood** • Variety of municipal, agricultural, and industrial contaminants, but effects not well understood. • Railway adjacent to population poses threat of spill. • Petroleum pipelines in 100-year floodplain need shutoff valves.	**Neutral—Poorly Understood** • Variety of municipal, agricultural, and industrial contaminants, but effects not well understood. • Railway near population poses threat of spill. • Fish kill in 1989 from tributary flood laden with wild fire ash. • Petroleum pipelines in 100-year floodplain need shutoff valves.	**Neutral—Poorly Understood** • Variety of municipal, agricultural, and industrial contaminants, but effects not well understood. • Fish kill in 2012 from tributary flood laden wild fire ash. • Petroleum pipelines in 100-year floodplain need shutoff valves.	**Neutral—Poorly Understood** • Variety of municipal, agricultural, and industrial contaminants, but effects not well understood. • No known fish kills.	**Neutral—Poorly Understood** • Variety of municipal, agricultural, and industrial contaminants, but effects not well understood. • Fish kill in 1990s from oil pipeline rupture. • Petroleum pipelines in 100-year floodplain need shutoff valves.	**Neutral—Poorly Understood** • Variety of municipal, agricultural, and industrial contaminants, but effects not well understood. • Threat of contaminant spill at Cameron Bridge on Little Colorado River is reduced by recent bridge reconstruction. • Fish killed or displaced in Shinumo Creek in 2014 by ash-laden flood and debris flow from wild fire.
6. Unimpeded range and connectivity	**Fair** • No impediment for movement to other populations in upper basin. • Fish passage installed at Price-Stubb, Grand Valley, Government Highline, and Redlands diversions for upstream movement; small number of adults captured in fish passage.	**Fair** • No impediment to movement to other populations in upper basin. • Fish passage installed at Price-Stubb, Grand Valley, Government Highline, and Redlands diversion for upstream movement; small number of adults captured in fish passage.	**Fair** • No impediment to movement to other populations in upper basin. • Fish passage installed at Tusher Wash diversion for downstream movement; small number of adults detected in fish passage.	**Fair** • No impediment to movement to other populations in upper basin. • Fish passage installed at Price-Stubb, Grand Valley, Government Highline, Redlands, and Tusher Wash diversions for upstream movement; small number of adults detected in fish passage.	**Fair** • No impediment to movement to other populations in upper basin.	**Fair** • No impediment to movement in mainstem above Lake Mead. • Natural falls or chutes impede movement to upper Little Colorado River, and to lower Shinumo and Havasu creeks. • Successful translocations of young fish above these falls.

Resource Category	Black Rocks	Westwater Canyon	Desolation/Gray canyons	Cataract Canyon	Dinosaur National Monument	Grand Canyon
7. Persistent populations	**Fair** • Population estimates declined from 880 in 1998 to 404 in 2012. • Annual reproduction and recruitment. • Four most recent estimates since 2007 indicate possible stabilization.	**Fair** • Population estimates declined from 3,520 in 1999 to 1,315 in 2012. • Annual reproduction and recruitment. • Four most recent estimates since 2007 indicate possible stabilization.	**Neutral** • Population estimates declined from 3,087 in 2001 to 1,672 in 2015. • Annual reproduction and recruitment. • Trend in adult abundance is statistically uncertain. • Less rigorous, catch-based monitoring over the past 30+ years starting in 1985 indicates potential stability.	**Neutral** • Adult numbers vary from 468 in 2003 to 295 in 2005; no recent estimates. • Apparent annual reproduction and recruitment. • Population has remained small but persistent since discovered in 1980. • Population trajectory is unknown.	**Bad** • Population is currently below detection limits and is now considered functionally extirpated. • Last collection of individuals in Yampa Canyon in 2004 and in Whirlpool Canyon in 2006. • Intervention in the form of translocations or hatchery stocking will be necessary to restore population.	**Fair** • Multistate model currently notes population at 12,000 in 2012. • Core Little Colorado River population appears to be stable, and fish in mainstem increasing in number and distribution. • Core Little Colorado River population is reproducing and recruiting annually. • Evidence of successful spawning in Havasu Creek and at two mainstem locations (RM 30, RM 214).
8. High genetic diversity	**Fair** • Black Rocks and Westwater populations are a subgroup of upper basin *Gila*, based on msat. • Exhibits highest level of introgression with Roundtail Chub. • Population is genetically diverse. • Genetic cluster may reflect spawning site fidelity and sites should be identified and protected.	**Fair** • Westwater and Black Rocks populations are a subgroup of upper basin *Gila*, based on msat. • Exhibits some level of introgression with Roundtail Chub. • Population is genetically diverse. • Genetic cluster may reflect spawning site fidelity and sites should be identified and protected.	**Fair** • A genetic subgroup of upper basin *Gila* separate from other subgroups and more similar to Roundtail Chub, based on msat. • Exhibits some level of introgression with Roundtail Chub. • Population is genetically diverse. • Genetic cluster may reflect spawning site fidelity and sites should be identified and protected.	**Fair** • A genetic subgroup of upper basin *Gila* closer to Desolation/Gray, based on msat. • Exhibits some level of introgression with Roundtail Chub. • Population is small but apparently genetically diverse. • Genetic cluster may reflect spawning site fidelity and sites should be identified and protected.	**Bad** • *Gila cypha* from Yampa Canyon is not genetically distinct, or may be absent, based on msat. • Evidence of hybridization with Roundtail Chub is high. • Population is functionally extirpated.	**Fair** • One subgroup of *Gila* for all Grand Canyon fish including aggregations, based on msat. • Population is genetically diverse with low and non-significant inbreeding coefficients, high levels of heterozygosity, and high allelic diversity. • Historic evidence of hybridization with Roundtail Chub and Bonytail, but no present introgression.

4.4 Ongoing Conservation Actions

The conditions of resources in the Colorado River System are managed through ongoing conservation actions designed to mitigate negative effects on the species. We consider these actions as part of the current condition of the resources because the ongoing conservation actions, and the programs that implement them, have been in place for decades. Three major programs in the Colorado River System are designed to balance demand for water, power, and recreation with protection of resources, including conservation of the Humpback Chub and other native species:

- The UCRRP coordinates recovery of the Humpback Chub, Colorado Pikeminnow, Razorback Sucker, and Bonytail upstream of Glen Canyon Dam;
- The Glen Canyon Dam Adaptive Management Program (GCDAMP) coordinates protection of natural resources of the Colorado River through the Grand Canyon, including the Humpback Chub and Razorback Sucker from Glen Canyon Dam to the Lake Mead inflow; and
- The Lower Colorado River Multi-Species Conservation Program (LCR MSCP) coordinates conservation of multiple species, including the Humpback Chub, Razorback Sucker, and Bonytail downstream of the Lake Mead inflow.

The UCRRP, GCDAMP, and MSCP were established in 1988, 1997, and 2005, respectively, and have implemented a suite of actions that benefit a variety of species. These actions are necessary for ameliorating human effects as well as effects of reduced water availability, and help to conserve the suite of native species that inhabit this region of the Colorado River. The following is a summary of conservation actions implemented by these programs that address each of the species needs categories for the Humpback Chub (Table 9)

1. **Diverse rocky canyon river habitat:** The general provisions of all three programs, and the commitments by the stakeholders ensure protection of habitats occupied by the Humpback Chub and the lands surrounding those habitats. Habitats occupied by the Humpback Chub are under the management of the Bureau of Land Management (Black Rocks, Westwater Canyon, and Desolation/Gray canyons), Canyonlands National Park and Glen Canyon National Recreation Area (Cataract Canyon), DNM (Yampa Canyon), and Glen Canyon National Recreation Area, Grand Canyon National Park, the Hopi Tribe, Navajo Nation, Hualapai Tribe, and Havasupai Tribe (Grand Canyon), and the Ute Tribe (Desolation Canyon). The federal agencies are all under the Department of the Interior, and the Native American Tribes are stakeholders that have a significant role in these programs. Humpback Chub populations are in the states of Utah, Colorado, and Arizona, that also provide protection for these habitats.

2. **Suitable river flow and temperature:** Flow and temperature recommendations have been developed for the major rivers of the upper basin, and even more importantly these recommendations have been applied (see Table 4 above). Revised flow management provides Humpback Chub with more natural and consistent flow conditions, which is a great improvement from past decades, especially the early 2000 drought period. Recommendations are evaluated through a series of UCRRP studies that are coordinated through study plans. Technical committees evaluate each study and recommend further actions through the program's annual planning documents. In the Grand Canyon, Glen Canyon Dam releases are coordinated through operating criteria in the LTEMP EIS (U.S. Department of the Interior 2016) and in the Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations of Lake Powell and Lake Mead EIS (U.S. Department of the Interior 2007).

   A temperature control device, installed on Flaming Gorge Dam in 1978, has warmed downstream releases for the Green River and allowed for upstream expansion of native fishes into Lodore Canyon (Bestgen et al. 2006). This warming could provide more suitable conditions for the reestablishment of the Humpback Chub population Whirlpool Canyon. In the lower basin, the Bureau of Reclamation has implemented feasibility studies for warming releases from Glen Canyon Dam. Warm releases from the dam starting in 2004 have provided insight to the possible beneficial effects of warming on native fishes in Grand Canyon, but warming could also benefit the nonnative fishes.

3. **Adequate and reliable food supply:** The general provisions of all three programs, including federal and state management actions help to protect the ecosystems of occupied habitats and surrounding lands. These provisions protect the health of the environment and promote production of invertebrates used as food by the Humpback Chub. In the Grand Canyon, where food supply has been altered, the LTEMP EIS includes studies to identify ways to improve the EPT populations (mayflies, stoneflies, caddisflies) through an evaluation of daily fluctuating dam releases.

4. **Habitat with few nonnative predators and competitors:** Predation and competition from nonnative fishes is one of the highest priority threats to the native fishes of the Colorado River System. As described in section 4.1.4, specific nonnative fish are of utmost management concern, and actions are being taken by each conservation program to control numbers of the most problematic species in both the upper and lower basins. Although Humpback Chub have no natural defense mechanisms, we propose that the harsh canyon habitats they inhabit are not as conducive to nonnative fish as the adjacent alluvial reaches.

   Upper Basin—The foundational document of the UCRRP recognized the threat and identified "Nonnative species and sportfishing management…" as one of five program elements to protect and recover the rare species in the upper basin (U.S.

Department of the Interior 1987). The UCRRP has implemented a number of plans and actions to manage nonnative fish, including the Nonnative Fish Management Policy, Integrated Stocking Plan, Yampa River Nonnative Fish Control Strategy, and upper Colorado River basin Nonnative and Invasive Aquatic Species Prevention and Control Strategy. The UCRRP and its partners currently remove problematic nonnative fish species from nine river reaches of the upper basin on the Yampa, Green, Colorado, White, Duchesne, and Gunnison rivers (Figure 26; Table 8). The species targeted for removal include: Smallmouth Bass, Northern Pike, Channel Catfish, Largemouth Bass, and Walleye, although other nonnative species are also removed as encountered. Additional projects are implemented at reservoir locations that contribute nonnative fish to downstream reaches. For FY 2017, the UCRRP spent ~41% of its $7 million annual operating budget on nonnative fish management.

Thorough scientific evaluations of the removal programs (e.g., Breton et al. 2014; Zelasko et al. 2014) guide implementation of removal activities, which currently focus on removing individuals from river habitats, disrupting in-river reproduction, and preventing escapement from upstream reservoirs. Removal efforts are adjusted annually to account for species ranges, densities, and environmental conditions. For example, in years with early onset of warm base flows, extra effort is applied to Smallmouth Bass removal, in order to limit production; similarly, as densities of Walleye increased in the late 2000s, extra effort was applied in target reaches, resulting in an apparent decline of Walleye catches by 2016 (Michaud et al. 2016).

Smallmouth Bass removal receives the highest effort in areas near Humpback Chub populations, such as Little Yampa Canyon upstream of the Dinosaur National Monument population; Walleye and Northern Pike are also removed at high rates in areas near Humpback Chub populations but are not found in high densities within the population areas (see section 4.1.4). Therefore, effort to remove these species within Humpback Chub habitats is reduced because densities are much lower. However, in years that densities are noticed to increase, commensurate increases in effort are applied. Nonnative fish are also removed duration population estimation work.

Nonnative fish in the upper Colorado River are removed primarily from the 106-km reach upstream of Black Rocks and Ruby-Horsethief Canyon (Loma, CO to Westwater Ranger Station, UT), where Smallmouth Bass production is highest; Smallmouth Bass, Largemouth Bass, Northern Pike have been removed from this area annually since 2004. Lower levels of removal take place downstream of Westwater Canyon and focus on Walleye. Removal of problematic nonnative fishes will continue in the areas adjacent to and in Black Rocks to thwart any sudden increase in numbers of nonnative fish that could be a threat to Humpback Chub.

In the Green River, nonnative fish are removed from Browns Park National Wildlife Refuge downstream to Canyonlands National Park, which includes Humpback chub populations in Desolation\Gray canyons and Whirlpool Canyon (DNM population). Most effort is applied to Smallmouth Bass, especially in areas such as Island Park and the middle Green River, but specific efforts are also applied to Walleye, Northern Pike, and White Sucker. Large Channel Catfish are removed as part of other sampling efforts.

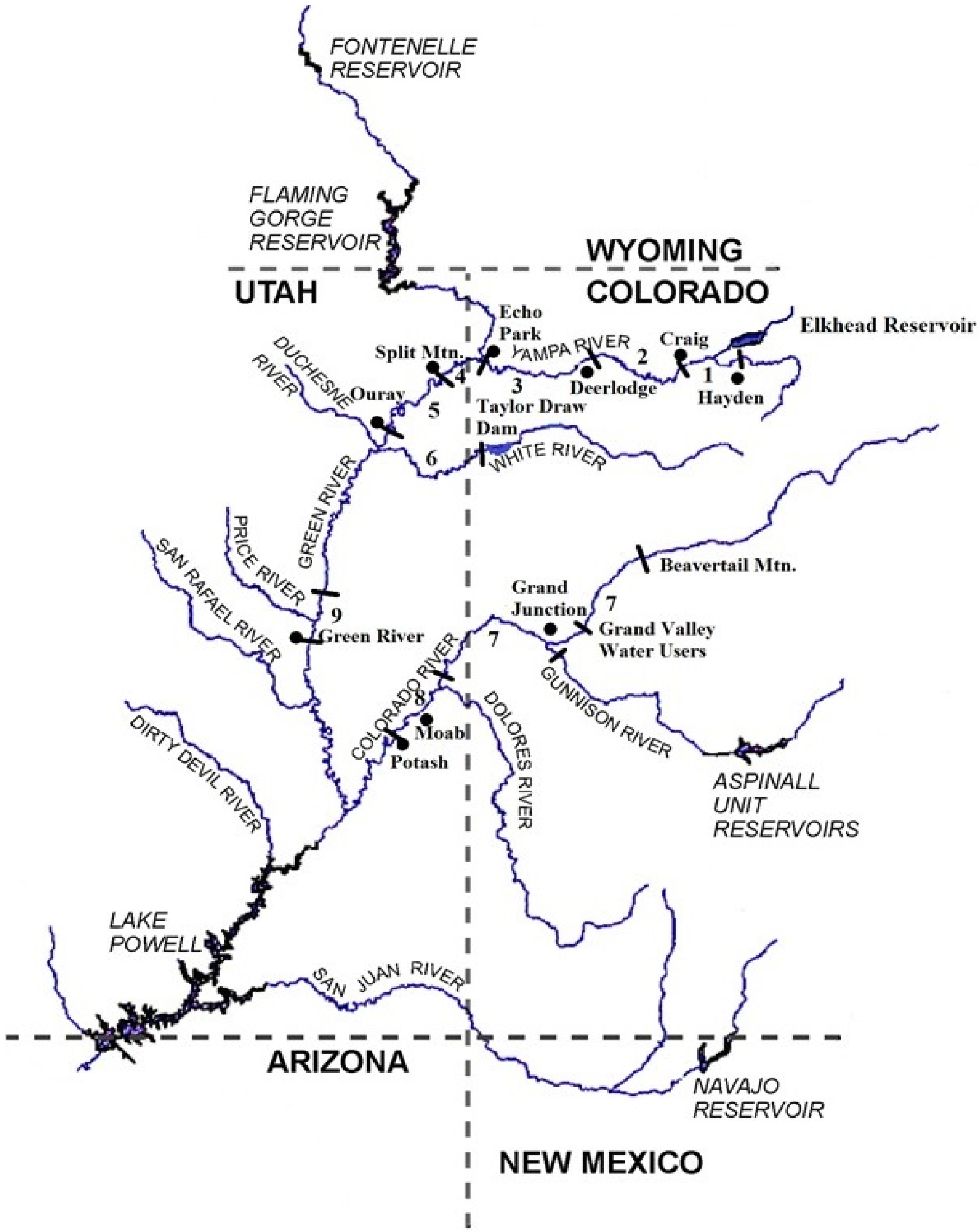

Figure 26. Reaches of the upper Colorado River basin from which target nonnative fish species are removed. Numbered reaches correspond to removal projects in Table 8.

Table 8. Ongoing projects of the Upper Colorado River Endangered Fish Recovery Program to reduce nonnative fish and sportfish impacts. Active removal projects are numbered and shown on Figure 26, as separate from research projects. Annual reports are available at: http://www.coloradoriverrecovery.org/documents-publications/work-plan-documents/project-annual-reports.html. NP = Northern Pike, SMB = Smallmouth Bass, WS = White Sucker, and WE = Walleye.

Project Name	River Reach	Purpose	Efficacy
1. Upper Yampa River Northern Pike Management	Yampa River: Hayden to Craig, CO (RM 160-151)	Remove NP, SMB, WS with multi-pass electrofishing and gill nets; 2005-2019	Reduce NP CPUE from 7.5 in 2005 to 2.6 in 2016
2. Middle Yampa River Northern Pike/Smallmouth Bass Management	Yampa River: Below Craig to Lily Park, CO (RM 134.2-50.5)	Remove NP and SMB with multi-pass electrofishing and gill nets; 2005-2017; includes a fishing tournament for SMB on Elkhead Reservoir	Adult NP and SMB CPUE reduced by >50% (2005 to 2016)
Supplement Middle Yampa River Smallmouth Bass and Northern Pike Management	Yampa River: Craig to DNM, CO (RM 151-47.5)	Remove NP and SMB with multi-pass electrofishing; 2008-2018	Reduce SMB abundance from 2418 in 2004 to 882 in 2016
Yampa River Fish Response	Little Yampa Canyon	Remove SMB from control and treatment reaches with electric seine; 2003-2018	Native fish abundance with removal of SMB from habitats
3. Lower Yampa River Nonnative Fish Management	Yampa Canyon (Deerlodge to Green River (RM 46-0)	Remove SMB with multi-pass electrofishing; 2004-2016	Reduce SMB CPUE from 21.6 fish/hr in 2004 to 8.62 in 2016
4. Green River Bass Management	Green River: Echo Park-Split Mtn. (RM 344.5-319.5) and DGC (RM 215.3-129.8)	Remove SMB with multi-pass electrofishing; 2004-2018	Reduce SMB CPUE in Echo to Split from 31.0 fish/hr in 2004 to 2.2 in 2016
5. Green River Bass Management	Green River: Split Mtn-Ouray (RM 344.5-207)	Remove SMB, NP, WE, WS with multi-pass electrofishing and fyke nets; 2010-2018	Adult SMB, NP, WE, WS CPUE reduced by >50% (2010 to 2016); periodic increases in young occur from reproductive success
Green River Fish Response	Middle Green River	Remove SMB and NP from control and treatment reaches with electrofishing; 2005-2011	CPUE of SMB and NP kept at low levels; project discontinued
Flaming Gorge Releases on Lodore/Whirlpool Fish Community	Green River: Lodore and Whirlpool canyons	To determine cumulative effect of flow and temperature regimes on SMB downstream of FGD; 2014-2018	Results being evaluated on effect of changes in flow and temperature on spawning SMB
6. Smallmouth Bass Control in White River	White River: Taylor Draw Dam to Green River confluence (RM 104.3-0)	Remove SMB with multi-pass electrofishing; 2012-2016	SMB CPUE reduced from 18.8 fish/hr in 2012 to 13.4 in 2016
7. Colorado River Smallmouth Bass Removal	upper Colorado River: Grand Valley Water User's (GVWU) dam, CO to Westwater UT; and Rifle to Beavertail Mountain, CO.	Remove SMB; 2004-2019	SMB CPUE reduced from 6.5 fish/hr in 2013 to 0.5 in 2016; periodic increases in young occur from reproductive success
8. Walleye Management	upper Colorado River: Cottonwood Wash below Westwater Canyon to Potash, UT (RM 112.3-47.2)	Remove WE and other problematic nonnative fish (e.g., SMB, NP, WS); 2014-2018	WE have been removed, but too soon to assess effect to numbers
9. Walleye Management	Green River: Tusher Diversion and Green River State Park (RM 128-120)	Remove WE and other problematic nonnative fish (e.g., SMB, NP, WS); 2014-2018	WE have been removed, but too soon to assess effect to numbers
Reservoir Management (various locations)	upper Colorado River basin	Nets and screens were installed to limit escapement of SMB, NP, and WE; In-reservoir removal; Harvest tournaments;	Limiting escapement from upstream reservoirs allows in-river removal to be more effective.
Population Dynamics Modeling, Smallmouth Bass	upper Colorado River basin	Assimilate database and develop a population dynamics model for SMB; 2009-2014	Population model developed for SMB to assess effect of SMB on native fish (Breton et al. 2015)
Population Dynamics, Northern Pike	Yampa River	Conduct comprehensive abundance and survival rate estimates for NP; 2011-2015	Estimates developed of abundance and survival of NP in Yampa River
Chemical Fingerprinting	upper Colorado River basin	Use strontium isotope signatures of otoliths to determine natal origins and hence, sources of invasion; 2006-2012	

In the Yampa River basin, Smallmouth Bass, Northern Pike, Channel Catfish, and Walleye removal takes place in Yampa Canyon. Nonnative fish removal is conducted at much higher levels upstream in locations like Little Yampa Canyon, Maybell, and Hayden to Craig. Northern Pike removal takes place upstream of Yampa Canyon as well, upstream as far as Steamboat Springs, Colorado.

Other basins, such as the Duchesne, White, and Gunnison rivers, receive nonnative fish removal effort as well. Despite having no Humpback Chub populations, removal in these reaches assists in basinwide control of these nonnative predators.

In addition to mechanical removal of nonnative fish in the upper basin, procedures for stocking nonnative fish have been developed under signed agreements between the U.S. Fish and Wildlife Service and the states of Colorado, Utah, and Wyoming that affect the Green River and upper Colorado River subbasins. These procedures identify the measures necessary to provide full evaluation of any species stocked in state waters and ensure that these introductions will not threaten native species.

Also, anti-escapement devices, such as downstream fish screens or in-reservoir nets, have been installed at the outlet of five small public reservoirs in the upper basin to reduce the numbers of nonnative fish that may escape to occupied habitat of native fishes.

The UCRRP is committed to applying a consistent, basin-wide nonnative fish management program that responds to annual conditions. For example, if increased densities of Smallmouth Bass are encountered in Desolation Canyon, or if flows will be conducive to their spawning, more effort will be applied in that location.

Lower Basin—A Nonnative Fish Control Environmental Assessment was implemented in the Grand Canyon in 2012 to help conserve native fish, particularly the Humpback Chub, by taking necessary actions to reduce numbers of nonnative fish, especially Rainbow Trout and Brown Trout in the Colorado River downstream of Glen Canyon Dam (U.S. Department of the Interior 2011). Efforts to mechanically remove nonnative fish were effective, but these target species recovered quickly after removal was suspended (Coggins 2008). The 2016 LTEMP EIS (U.S. Department of the Interior 2016) and the 2013 Comprehensive Fisheries Management Plan (National Park Service 2013) help to define future actions for controlling nonnative fish in the Grand Canyon. Although mechanical nonnative fish control strategies are in place in Grand Canyon, it is uncertain if mechanical removal in the mainstem Colorado River would be effective during large Rainbow Trout recruitment years, and/or if Brown Trout continue to increase in abundance in Glen Canyon and other areas and expand into the LCR inflow area.

Two major projects have removed large numbers of brown trout from the Grand Canyon in an attempt to evaluate the efficacy of a large scale non-native fish removal to benefit native fishes: (1) mainstem electrofishing in the vicinity of the LCR from 2003 to 2006, and (2) installation and operation of a fish weir to trap fish moving into and from Bright Angel Creek from 2006 to 2007 and 2010 to 2016.

During 2003-2006, over 23,000 nonnative fish, including rainbow trout (19,020; 82%) and brown trout (479; 1%), were removed from a 9.4-mile reach of the Colorado River near the LCR (Coggins 2008). These removals resulted in a rapid shift in fish community composition from one dominated by cold water salmonids (>90%), to one dominated by native fishes and the nonnative fathead minnow (>90%). Concurrent with the mechanical removal, data collected within a control reach of river suggested a systemic decline in rainbow trout unrelated to the fish removal effort. Thus, the efficacy of the mechanical removal was aided by an external systemic decline, particularly in 2005-2006. Subsequent sampling in the reach shows that the numbers of rainbow trout and brown trout was higher after increases starting in 2008, but these data sets may not be comparable after removal was suspended (Makinster et al. 2010).

The second effort to control nonnative fish, specifically brown trout, was implemented in 2006 in Bright Angel Creek. As recently as the 1970s, brown trout were rare in Bright Angel Creek (Carothers and Minckley 1981), despite this being one of the original stocking locations in 1926. After the 1990s, however, brown trout became a predominant component of the fish community in the creek, and a corresponding decline in native fish such as speckled dace was observed (Otis 1994). Bright Angel Creek is now a principal spawning site for brown trout, and a large aggregation is found in the Colorado River near the confluence with Bright Angel Creek (Valdez and Ryel 1995; Makinster et al. 2010).

In an attempt to restore the native fish community of Bright Angel Creek, and to reduce the threat of predation to Humpback Chub in the Colorado River, an ambitious program of mechanical removal of nonnative trout was implemented. In 2002–2003, a temporary weir was put in place that captured over 400 brown trout as part of a feasibility study (Leibfried et al. 2005; Figure 5). In 2006, the Bright Angel Creek Trout Reduction Project Environmental Assessment (EA) and Finding of No Significant Impact (FONSI; NPS 2006) identified goals and a strategy for reducing brown trout. This project was initiated in cooperation with the U.S. Fish and Wildlife Service in 2006-2007 (NPS 2006; Sponholtz et al. 2010) following the feasibility study conducted in 2002-2003 (Leibfried et al. 2005). This effort was resumed in 2010 (Trammell et al. 2012) following the 2008 and 2011 Biological Opinions on the Operation of Glen Canyon Dam that identified conservation measures to conduct trout reduction in Bright Angel Creek and to establish population redundancy of Humpback Chub in Grand Canyon tributaries (USFWS 2008, USFWS 2011).

Current operations under the Bright Angel Creek trout control project were established through the NPS Comprehensive Fisheries Management Plan (NPS 2013). From 2010-2012, trout reduction efforts included the installation and operation of a weir and backpack electrofishing the lower 2900 m of the creek (confluence to Phantom Creek; Trammell et al. 2012). Beginning in the fall of 2012, removal efforts were expanded to encompass the entire length of Bright Angel Creek (approximately 16 km) and Roaring Springs (approximately 1.5 km). The operation of the weir was also extended from October through February to capture greater temporal variability in the trout spawn (Trammell et al. 2012; NPS 2013). Removal efforts also occurred in the mainstem Colorado River near the Bright Angel Creek inflow in 2014 to 2016. This brown trout removal effort has continued annually from 2010 to 2017 (Schelly et al. 2017). There was also an increase in the number of Brown Trout in the Lees Ferry Reach starting in 2013, but a significant decline elsewhere in the mainstem (Rogowski et al. 2017). A special workgroup has been convened in 2017 to identify causes for expansion of Brown Trout and strategies for controlling numbers.

In the Grand Canyon, passage of nonnative fish from Lake Powell through the dam penstocks and generators has been identified by the Bureau of Reclamation as possibly increasing as reservoir elevation becomes lower and warm epilimnetic water is released through the dam. Coordinated removal of Green Sunfish, thought to have escaped through the dam, was conducted by the NPS, USGS, and AGFD in the Lees Ferry reach in 2016 and 2017, and the NPS remains vigilant to new species invasions and increases of existing species. Large numbers of Green Sunfish were discovered in a large isolated backwater in the Lees Ferry reach in 2015 and 2016. It is believed that these fish escaped through Glen Canyon Dam, and the National Park Service coordinated an interagency rapid response to remove the fish. The backwater or slough was treated with rotenone in November 2015[9], and with liquid ammonia in October 2016 (Ward 2016) and most of the fish were removed. Long-term strategies are described in a Comprehensive Fisheries Management Plan (National Park Service 2013) for dealing with these new invasions and expansions. Currently, nonnative fish in the Grand Canyon could potentially limit the Humpback Chub population, and resource management agencies are developing and implementing plans to control these species.

5. **Suitable water quality:** The states of the Colorado River System each have Hazardous Materials (HAZMAT) plans, but these have not been reviewed and evaluated to determine how to implement measures to mitigate contaminant spills in ways that protect the fish. Several pipelines are within the river floodplain, but these have not been identified and shut-off valves have not been installed. The Atlas Mills tailings continue to be removed from the Moab site. Some studies of selenium and

[9] see: https://www.nps.gov/glca/learn/news/Rapid-Response-Treatment-to-Remove-Invasive-Green-Sunfish-from-a-Backwater-Slough.htm

mercury effects on endangered fish have been done, but the effect of these elements on Humpback Chub remain uncertain. Selenium remediation has been implemented in the Gunnison River and sources of selenium have been tied to flow control in the Green River (e.g., Stewart Lake). In the lower basin, the bridge over the LCR and intersection of US 89 and SR 64 at Cameron, AZ was reconstructed in fall 2016, reducing the threat of hazardous materials spills reaching the principal spawning area of the Humpback Chub.

6. **Unimpeded range and connectivity:** Fish passage structures have been installed on all five water diversion structures in the upper basin on the Gunnison, upper Colorado, and Green rivers. These fish passages provide for upstream movement of fish and are either non-selective, where all fish are allowed to pass, or selective where nonnative fish are removed from the system and only native species are allowed to pass. These fish passage structures allow access by native fish to the more productive upstream reaches of historical range and could allow for population increases and expansions. Remote PIT-tag antennas at these fish passages have detected small numbers of tagged Humpback Chub moving upstream through these structures.

   In the lower basin there are no impediments to movement in the mainstem Colorado River above Lake Mead. Natural falls or chutes impede movement to the upper Little Colorado River, and to lower Shinumo and Havasu creeks. However, successful translocations have moved young fish above these falls. Glen Canyon Dam continues to be a barrier to mixing between the upper and lower basin.

7. **Persistent populations:** The upper basin populations of Humpback Chub are each monitored on a regular basis (2 consecutive years of 4) to estimate the numbers of adults and sub-adults, as well as recruitment and survival rates. Provisions have been put in place in the upper basin to minimize entrainment in canals and losses especially of young fish from populations. Fish screens or weir walls have been installed at the three canals in the upper basin on the Gunnison, upper Colorado, and Green rivers. These structures reduce losses of native fishes to canals where the water is released onto fields or the fish become stranded from seasonal drying.

   The lower basin population of Humpback Chub are monitored annually over the past three decades. The most recent modeling effort incorporates skip spawning behavior into a multistate model. The core Little Colorado River population appears to be stable, reproducing, and recruiting; fish in mainstem increasing in number and distribution. Evidence of successful spawning has been detected in Havasu Creek and at two mainstem locations (RM 30, RM 214).

8. **High genetic diversity:** Currently, no broodstock or refuge population of Humpback Chub from the upper basin exists in a hatchery facility, but a small number of adults from Black Rocks were taken to the Horsethief ponds near Grand Junction, CO,

where the fish have reproduced. Fish collected from the Yampa River and transferred to hatchery facilities turned out to be Roundtail Chub or hybrids. A refuge population of ~1,000 wild Humpback Chub, taken as young fish from the LCR, has been established at the Dexter SNARRC. Evaluation of these fish shows that they have high genetic diversity. A broodstock has not been established from these fish. Fish that are translocated in the Grand Canyon are captured as live, 2–4 month old fish, taken to SNARRC for grow-out, cleansed of parasites and diseases, and returned to Grand Canyon as PIT-tagged individuals. This strategy of using wild mixed fish ensures that genetic diversity is maintained throughout the canyon (Pine et al. 2013).

Table 9. Species needs categories, associated conservation actions, effect of actions, and benefit to the Humpback Chub.

Species Needs	Conservation Action	Effect of Action	Benefit to Humpback Chub
1. Diverse rocky canyon river habitat	Upper Basin: • Occupied habitats and surrounding lands are managed to conserve resources by BLM[a], CNP[b], DNM[c], GCNRA[d] and states of CO and UT.	Upper Basin: • Agencies regulate recreation and mining that protect habitat in the long term.	Upper Basin: • Occupied critical habitat is protected from direct human alteration.
	Lower Basin: • Occupied habitats and surrounding lands are managed to conserve resources by GCNRA, GCNP[e], and state of AZ, as well as the Hopi Tribe, Navajo Nation, Hualapai Tribe, and Havasupai Tribe.	Lower Basin: • Agencies regulate recreation and mining that protect habitat in the long-term.	Lower Basin: • Occupied critical habitat is protected from direct human alteration.
2. Suitable river flow & temperature	Upper Basin: • The Bureau of Reclamation and upper Colorado River basin water managers have changed their operations to achieve flow and temperature recommendations for the endangered fish in the Colorado River (Osmundson et al 1995; McAda 2003), Green River (Muth et al. 2000), and Yampa River (Roehm 2004; USFWS 2005a – See Table 4 for more detail). • In 2007, the Recovery Program secured a permanent source of summer augmentation water (5000 ac-ft with an option to lease an additional 2000 ac-ft) in Elkhead Reservoir in the upper Yampa River drainage. • Collaboration among UCRRP, Reclamation, and The Nature Conservancy to address reduced water availability.	Upper Basin: • Operations to meet flow and temperature recommendations benefit native chubs • Flow recommendations provide foundation to support life stages of Humpback Chub. • Ongoing and long term commitments to flow management improves habitat for various life stages of Humpback Chub. • Promotes concepts of the Natural Flow Paradigm (Poff et al. 1997) expected to favor native over nonnative species. • Provisions for reduced water availability help to address low stream flows. • Improve summer base flow conditions in the Yampa River.	Upper Basin: • High spring flows cleanse substrate of silts for successful spawning. High spring flows minimize invasion by hybridizing Roundtail Chub. • Increased magnitude and duration of the spring peaks reduces influxes of nonnative Smallmouth Bass. Adequate base flows provide swift current that minimizes Smallmouth Bass spawning habitat • Floods deliver organic matter for food production. • Reliable flows ensure habitat sustainability. • Flow management on the Yampa River could benefit a future Humpback Chub repatriation effort in DNM, deemed necessary. • Population response is uncertain and expected to take one or two generations to exhibit. Population estimates in 2018-2023 will determine if flow and temperature management is effective.
	Lower Basin: • LTEMP EIS for Operation of GCD[f] (U.S. Department of the Interior 2016) establishes flow regimes. • Bureau of Reclamation has implemented feasibility studies for warming releases from GCD as part of the LTEMP EIS. • MSCP Habitat Conservation Plan (U.S. Department of the Interior 2016).	Lower Basin: • GCD releases are designed to not adversely affect the Humpback Chub. • Warm releases from GCD starting in 2004 enable greater growth by Humpback Chub, but may allow for expansion of nonnative fish in the Grand Canyon. • MSCP funds help to evaluate Humpback Chub expansion into western Grand Canyon.	Lower Basin: • Moderate daily flow changes may improve aquatic insect production as food for fish. • High flow experiments help to maintain backwaters and stimulate primary production. • Warmer dam releases improve fish growth. • Possible future modifications to warm dam releases could allow for mainstem spawning.

Species Needs	Conservation Action	Effect of Action	Benefit to Humpback Chub
3. Adequate and reliable food supply	Upper Basin: • General provisions of all three programs and federal and state management ensure protection of occupied habitats and surrounding lands.	Upper Basin: • Food supply is protected with protection of occupied habitats and surrounding lands.	Upper Basin: • Sustained food supply is critical to growth and survival of young and for recruitment.
	Lower Basin: • LTEMP EIS includes studies to identify ways to improve food supply in the mainstem.	Lower Basin: • Studies are ongoing to evaluate EPT populations (mayflies, stoneflies, and caddisflies) and effect of daily fluctuating dam releases.	Lower Basin: Food supply in Grand Canyon may be limited and moderate daily flow changes may improve aquatic insect production.
4. Habitat with few nonnative predators and competitors	Upper Basin: • Thorough scientific evaluations of removal efforts guide implementation of field actions (Breton et al. 2014; Zelasko et al. 2014) to disrupt in-river reproduction and prevent reservoir escapement. • Nonnative fish removal efforts are ongoing in the Green, Yampa, and upper Colorado rivers (and other basins that do not contain Humpback Chub). • Upper Colorado River Basin Nonnative and Invasive Aquatic Species Prevention and Control Strategy completed (Martinez et al. 2014). • Procedures for stocking nonnative fish species in the upper Colorado River basin, revised (USFWS 2009c). • Fish screens to prevent escapement of nonnative fish. • Harvest regulations in the states of Utah and Colorado promote removal of nonnative species.	Upper Basin • Removal efforts have reduced numbers of nonnative fish, but some populations rebound when removal is suspended. • UDWR has a must kill policy on all Northern Pike, Walleye, Smallmouth Bass, and Burbot caught in the Green River; Colorado has unlimited catch regulations for the same species. • Fish screens have been installed at: Elkhead Reservoir (2007 and 2016, Yampa River), Starvation Reservoir (2015, Duchesne River), Rifle Gap Reservoir (2013, Rifle Creek, upper Colorado River), Highline Reservoir (1999, Mack Wash, upper Colorado River), Juniata Reservoir (Gunnison River), and various small riverside ponds near Grand Junction, CO.	Upper Basin • Reducing numbers of nonnative fish will improve survival of young, enhance recruitment, and increase population size and age structure. • Fewer nonnative fish will reduce competition with native fish over space and food. • Fewer nonnative fish will reduce species of parasites and diseases and incidence of infestation. • Population response is uncertain and is expected to take one or two generations to manifest. Population estimates in 2018-2023 will determine if nonnative and habitat management has resulted in population response.
	Lower Basin: • LTEMP EIS and Nonnative Fish Control EA. • Arizona Game Commission has implemented no fishing regulations for the area around the LCR to prevent incidental take of Humpback Chub. • Conservation Plan (LCR MSCP 2004) provides guidance for nonnative fish management in Lake Mead and western Grand Canyon. • State of Arizona currently has restrictions for stocking nonnative fish waters in and near the Grand Canyon. • Escape of nonnative fish from Lake Powell through the GCD penstocks and generators is being evaluated.	Lower Basin: • Removal of Rainbow Trout and Brown Trout has been implemented and evaluated. • Triggers have been developed in the LTEMP EIS to implement nonnative fish removal. • Restrictions to stocking nonnative fish will continue, but many nonnative fish species already occur. • Nonnative fish occur in Grand Canyon tributaries and in Lakes Powell and Mead, but no provisions are in place for exclusion devices or strategies. • Lower elevation of Lake Powell may lead to an increase in fish passing through the penstocks.	Lower Basin • Reducing numbers of nonnative fish will improve survival of young, enhance recruitment, and increase population size and age structure. • Fewer nonnative fish will reduce competition with native fish over space and food. • Fewer nonnative fish will reduce species of parasites and diseases and incidence of infestation.

Species Needs	Conservation Action	Effect of Action	Benefit to Humpback Chub
5. Suitable water quality	Upper Basin: • State HAZMAT plans have not been reviewed. • Pipeline crossings have not been identified and shutoff valves have not been installed. • Atlas Mills tailings continue to be removed. • Some studies of selenium and mercury effects on endangered fish completed, but effects remain uncertain. • Selenium remediation has been implemented in the Gunnison River and sources of selenium (e.g., Stewart Lake) have been tied to flow control.	Upper Basin: • Would prevent or reduce incidence of hazardous-materials spills. • Would reduce the amount of toxic spills. • Would remove toxic materials from the river bank. • Identifies primary sources of selenium • Determines concentrations in water and fish. • Identifies harmful concentrations.	Upper Basin: • Hazardous-materials spills can have catastrophic effects on populations by killing large numbers of fish, causing stress and disease, and eliminating entire year classes that result in failed recruitment and reduced population size. • Water contaminants can have insidious effects on fish physiology, including detrimental effects on reproduction, growth, and survival. • Selenium remediation helps to reduce selenium, which can negatively affect fish reproduction and survival.
	Lower Basin: • The bridge over the LCR and intersection of US 89 and SR 64 at Cameron, AZ has been reconstructed. • Arizona Department of Environmental Quality promotes and enforces clean water standards throughout the State, including the Grand Canyon.	Lower Basin: • Bridge reconstruction reduced the threat of a hazardous materials spill in the LCR that could reach the spawning area of the Humpback Chub. • Enforcement of clean water regulations help to reduce toxic contaminants.	Lower Basin: • Completion of the bridge and intersection at Cameron in fall 2016 has reduced the risk of a catastrophic spill that could kill large numbers of fish in the LCR. • Water contaminants can have insidious effects on fish physiology, including detrimental effects on reproduction, growth, and survival.
6. Unimpeded range and connectivity	Upper Basin: • Fish passage structures have been installed at Redlands Water and Power Company Diversion on the Gunnison River (1996); Grand Valley Irrigation Company Diversion (1998), Grand Valley Project Diversion (2005), and Price-Stubb Diversion on the upper Colorado River (2008); Craig Diversion on the Yampa River (1992); and Tusher Diversion on the Green River (2016).	Upper Basin: • Small numbers of Humpback Chub have been caught at fish passage structures in the upper basin indicating that the fish are free to move and possibly establish new populations or exchange with existing populations.	Upper Basin: • Unimpeded movement allows the fish to move among population for genetic exchange and maintain genetic diversity of populations. • Providing additional range could allow fish to move into unoccupied but suitable habitat and start new populations.
	Lower Basin • Fish passage has not been installed in Humpback Chub habitat of the lower basin, but wild fish have been translocated upstream of waterfall and chutes in the upper LCR, Shinumo Creek, and Havasu Creek.	Lower Basin: • Successful translocations of fish in Grand Canyon demonstrate the ability of the Humpback Chub to be moved and to adjust to new locations.	Lower Basin: • Unimpeded movement allows the fish to move among aggregations for genetic exchange to maintain genetic diversity, and for augmenting aggregations, and possibly to establish a mainstem population. • Translocating fish to tributaries provides additional groups of fish for redundancy and may lead to establishment of new populations that provide resiliency in case of a loss of other populations.

Species Needs	Conservation Action	Effect of Action	Benefit to Humpback Chub
7. Persistent populations	Upper Basin: • Populations are monitored on a regular basis to estimate the numbers of adults and sub-adults, as well as recruitment and survival rates. • Fish screens or weir walls have been installed to reduce entrainment at Redlands Water and Power Company Diversion (2005, Gunnison River); Grand Valley Irrigation Company Diversion (2002), Grand Valley Project Diversion (2006), Price-Stubb Diversion (2014, upper Colorado River), and Tusher Wash Diversion (Green River).	Upper Basin: • Annual population estimates are done for two consecutive years in every two years in Desolation/Gray, Westwater and Black Rocks. The Cataract population is monitored biennially by assessing long-term catch rate trends. • Fish screens and weir walls on canals reduces loss of fish through entrainment.	Upper Basin: • Monitoring the fish annually helps to assess population size and structure and to identify problems with decline of numbers. • Fish screens and weir walls will reduce loss of fish and enhance survival, recruitment, and population structure and size.
	Lower Basin: • The population and aggregations are monitored on a regular basis to estimate the numbers of adults and sub-adults, as well as recruitment and survival rates. • Escape of fish through the GCD penstocks has been evaluated (Hart and Sherman 1996; Reclamation 2012b)	Lower Basin: • Annual population estimates are done annually in the LCR and periodically in aggregations. • Some escape of nonnative fish is reported through GCD, but the effect to downstream fish has not been evaluated.	Lower Basin: • Monitoring the fish annually helps to assess population size and structure and to identify problems with decline of numbers. • Monitoring helps to identify new fish so that control measures can be implemented to reduce effects of predation and competition.
8. High genetic diversity	Upper Basin: • Initial genetics analysis completed (Douglas and Douglas 2007). • Fish collected from the Yampa River and transferred to hatchery facilities determine to be Roundtail Chub. • No upper basin Humpback Chub refuge population or broodstock currently exist.	Upper Basin: • Initial genetic analysis shows genetic diversity from decadal scale exchange of individuals among populations. • Humpback Chub are not currently being stocked in the upper basin.	Upper Basin: • Maintaining genetic diversity among upper basin populations is important to ensure that fish maintain adaptive traits for reproduction, growth, and survival. • Humpback Chub are not currently stocked in the upper basin, but stocking may be appropriate to return fish to historical habitat (e.g., Yampa and Whirlpool canyons) and to establish new populations in suitable habitat. • Reestablished and new populations will provide redundancy and resiliency.
	Lower Basin: • Conservation Plan (LCR MSCP 2004) provides guidance for stocking procedures for native fish in the lower basin. • Genetic evaluation has been done for refuge population from Grand Canyon (Wilson 2014) and for wild fish translocated in Grand Canyon. • Refuge population of ~2,000 fish currently at Dexter SNARRC.	Lower Basin: • Wild Humpback Chub may continue to be translocated in the Grand Canyon. • Humpback Chub are not currently being stocked by the MSCP.	Lower Basin: • Maintaining genetic diversity throughout Grand Canyon is important to ensure that fish maintain adaptive traits for reproduction, growth, and survival. • Translocated fish in historical habitat may help to establish new populations. • Reestablished and new populations will provide redundancy and resiliency.

[a] BLM = Bureau of Land Management [b] CNP = Canyonlands National Park [c] DNM = Dinosaur National Monument [d] GCNRA = Glen Canyon National Recreation Area
[e] GCNP = Grand Canyon National Park [f] GCD = Glen Canyon Dam

4.5 Status of Populations

This section describes the demographic status of each of the six Humpback Chub populations. Although these populations have existed for millennia, most were described in only the last 35–50 years:;Black Rocks in 1976 (Kidd 1977); Westwater Canyon in 1979 (Valdez and Clemmer 1982); Desolation/Gray canyons in 1967 (Holden 1973); Cataract Canyon in 1980 (Valdez et al. 1982); and Yampa Canyon in 1968 (Holden 1973). Humpback Chub were photographed in the Grand Canyon in 1911 (Kolb and Kolb 1914), and the species was described from a holotype specimen caught by an angler in 1933 (Miller 1946).

Upper basin populations were first sampled in the 1960s and 1970s, but indices of fish abundance began in 1986 with the Interagency Standardized Monitoring Program (ISMP). The ISMP initially used catch rates (CPUE), adding mark-recapture abundance estimates in 1998. In the Grand Canyon, Humpback Chub were first surveyed in the early 1960's as part of the Glen Canyon Dam pre-impoundment studies (see references in Valdez and Ryel [1995], Webb et al. [2002]). Post-impoundment studies were conducted during 1977-78 (Minckley 1980; Carothers and Minckley 1981; Minckley 1997), and during 1987–1990 (Minckley 1988, 1989, 1997). Mark-recapture estimates began in 1987 in the LCR (Douglas and Marsh 1996) and in 1991 in the mainstem (Valdez and Ryel 1995).

Obtaining mark-recapture estimates and CPUE indices is highly challenging because of the notorious difficulty in sampling Humpback Chub in their habitats. Reliable abundance estimates are not available for young and sub-adult Humpback Chub in the upper basin because of the difficulty of capturing fish and distinguishing them from sympatric Roundtail Chub and Bonytail. The age structure, survival, and recruitment of the Grand Canyon population have been quantified and provide additional information on population persistence.

Abundance estimates of Humpback Chub are available for the upper basin over the last 17 years (1998–2016; Table 10), though not annually for any single population, and for the last 23 years (1989–2012) in the Grand Canyon. This period of monitoring is but a snapshot in the historical pattern of population numbers, and the long-term dynamics of these populations are not well understood. If generation time for the species is 8 years (see section 5.1), quantitative monitoring has been conducted for less than three generations.

Persistence in this assessment is inferred through population models to compute the intrinsic rate of growth or lambda (λ) for each population. Each lambda value was derived as 1 minus the slope of the regression model fit to natural log-transformed adult abundance estimates. The 95% confidence interval for lambda was computed as the standard error of the slope times 1.96. Akaike information criterion scores adjusted for small samples sizes (AIC_c) were used to help determine the model of best fit (Table 11).

Table 10. Annual population estimates for adult Humpback Chub (age 4+, ≥ 200 mm TL) in the five upper basin populations. N = population estimate, Low CI = lower 95% confidence interval, High CI = upper 95% confidence interval, "--" = no estimate. The 2016 estimate for Westwater Canyon is preliminary and therefore italicized.

Year	Black Rocks[a]			Westwater Canyon[b]			Desolation/Gray canyons[c]			Cataract Canyon[d]			Yampa Canyon[e]		
	N	Low CI	High CI	N	Low CI	High CI	N	Low CI	High CI	N	Low CI	High CI	N	Low CI	High CI
1998	880	572	1,431	6,747	4,001	11,636	--	--	--	--	--	--	--	--	--
1999	994	810	1,245	3,520	2,513	4,979	--	--	--	--	--	--	--	--	--
2000	740	490	1,150	2,266	1,742	2,975	--	--	--	--	--	--	317	184	623
2001	--	--	--	--	--	--	3,087	0	9,138	--	--	--	320	245	438
2002	--	--	--	--	--	--	16,931	0	34,455	--	--	--	277	157	512
2003	590	350	1,040	2,520	1,814	3,554	6,935	1,742	12,127	468	217	1,705	224	123	434
2004	560	360	950	2,724	2,034	3,689	--	--	--	273	144	589	--	--	--
2005	--	--	--	2,000	1596	2,530	--	--	--	295	155	652	--	--	--
2006	--	--	--	--	--	--	2,856	1,550	4,162	--	--	--	--	--	--
2007	283	179	478	1,212	972	1,532	1,794	788	2,801	--	--	--	--	--	--
2008	395	250	655	1,139	954	1,379	--	--	--	--	--	--	--	--	--
2009	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2010	--	--	--	--	--	--	2,520	445	4,594	--	--	--	--	--	--
2011	379	239	642	1,467	1,175	1,861	--	--	--	--	--	--	--	--	--
2012	404	298	571	1,315	1,022	1,713	--	--	--	--	--	--	--	--	--
2013	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2014	--	--	--	--	--	--	1,863	924	2,802	--	--	--	--	--	--
2015	--	--	--	--	--	--	1,672	756	2,589	--	--	--	--	--	--
2016				*2,002*	*1,118*	*2,886*									

[a] Francis and McAda (2011); revised by Francis et al. (2016)
[b] Estimates for 1998-2016 from Hines et al. (2016)
[c] Jackson and Hudson (2005); Badame (2010, 2011); revised by Howard and Caldwell (2017); estimates for 2001–2003 unreliable, of low precision, not recommend for analysis
[d] Badame (2008)
[e] Haines and Modde (2002); Finney (2006)

Table 11. One- and two-phase models to determine lambda trajectories based on adult abundance estimates for three populations of Humpback Chub (provided by C. Yackulic, Grand Canyon Monitoring and Research Center, U.S. Geological Survey). The years and total number of abundance estimates (n) are provided in parentheses after each population name. Lowest AIC_c values (AIC_c is used when few point estimates contribute to the model) determine best model, also indicated in bold.

Population	AIC_c	β_0	B_1	B_2	λ_1 (95% CI)	λ_2 (95% CI)
Black Rocks (1998-2012, n=9)						
One-phase (linear) model	**6.9**	**6.3**	**-0.07**		**0.93 (0.90–0.96)**	
Two-Phase (separate lambda trajectories) model	10.5	6.1	-0.12	-0.03	0.88 (0.81–0.94)	0.97 (0.91–1.03)
Westwater Canyon (1998-2016, n=11)						
One-phase (linear) model	**17.8**	**7.7**	**-0.06**		**0.94 (0.89–0.98)**	
Two-Phase (separate lambda trajectories) model	18.5	7.5	-0.16	-0.01	0.84 (0.75–0.94)	0.99 (0.93–1.05)
Grand Canyon (1989-2008, n=20)						
One-phase (linear) model	-3.7	8.77	-0.03		0.97 (0.96–0.99)	
Two-Phase (separate lambda trajectories) model	**-67.5**	**8.47**	**-0.07**	**0.07**	**0.93 (0.93–0.94)**	**1.07 (1.06–1.08)**

4.5.1 Black Rocks—The Black Rocks population occupies the smallest geographic area (1.4 km) of the six Humpback Chub populations. The estimated number of adults (≥ 200 mm TL) has ranged from 994 in 1999 to 283 in 2007 (Figure 27A; Table 10). The latest estimate is 404 adults in 2012, and the average of the nine estimates is 581 adults. These estimates declined from the beginning of the census in 1998, but leveled off from 2007 to 2012, with the last three estimates approximately equal at ~400 adults. The adult CPUE indices are also similar from 2003 to 2012, following lower indices from 1988 to 1997 and highest indices in 1998 and 1999 that correspond with the highest adult abundance estimates (Figure 27B).

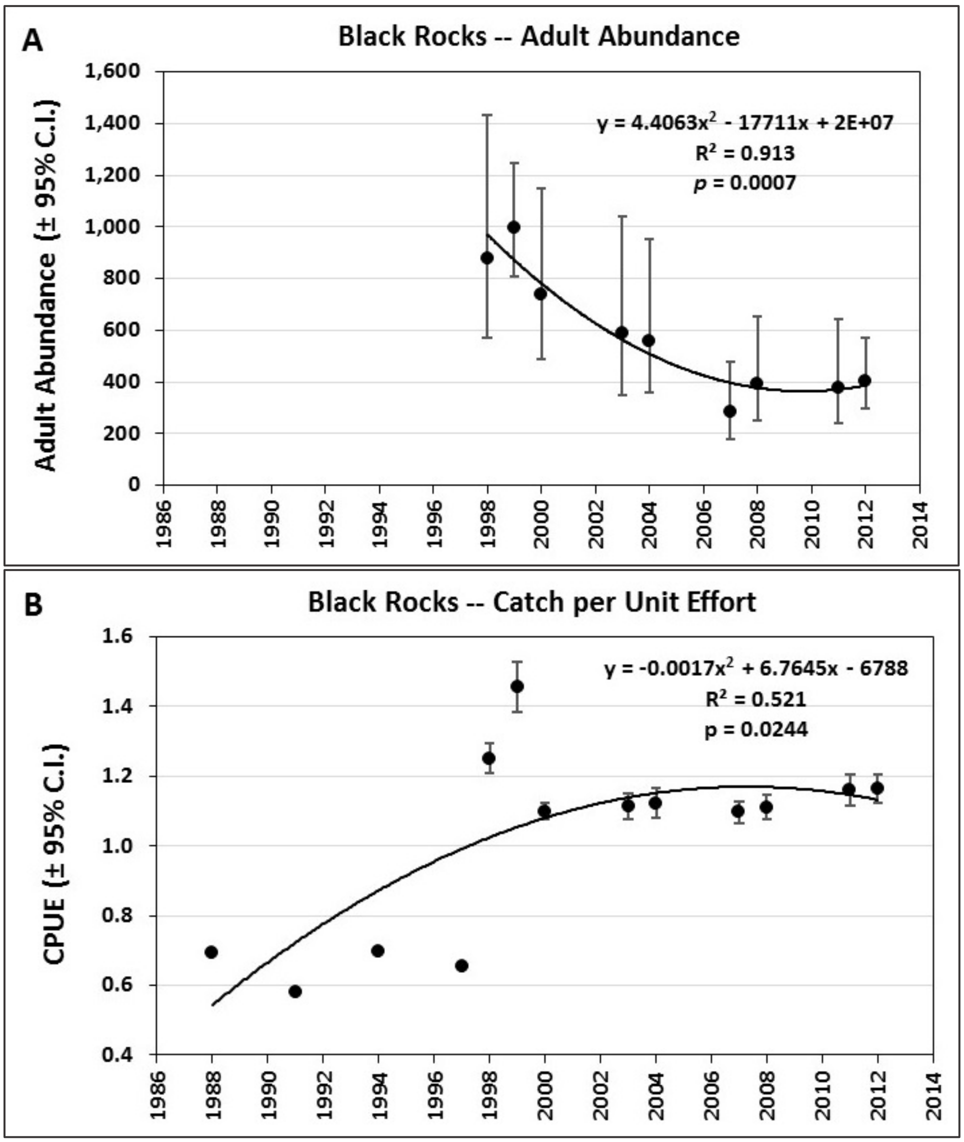

Figure 27. Line of best fit for (A) annual abundance (1998–2012) and (B) trammel net CPUE (1988–2012) of adult Humpback Chub in the Black Rocks population. Adult abundance estimates from Francis et al. (2016). CPUE data provided by Travis Francis (U.S. Fish and Wildlife Service, Personal Communication, August 2016).

Population Trajectory and Lambda—A retrospective analysis of the nine abundance estimates over a period of 15 years (1998–2012) shows that the number of adults in Black Rocks has declined since mark-recapture abundance estimates were initiated in 1998, as indicated by a single intrinsic growth rate (λ) of 0.93 (95% C.I. = 0.90-0.96; Figure 28). Since 2007 declines have potentially been arrested and population estimates are stabilizing

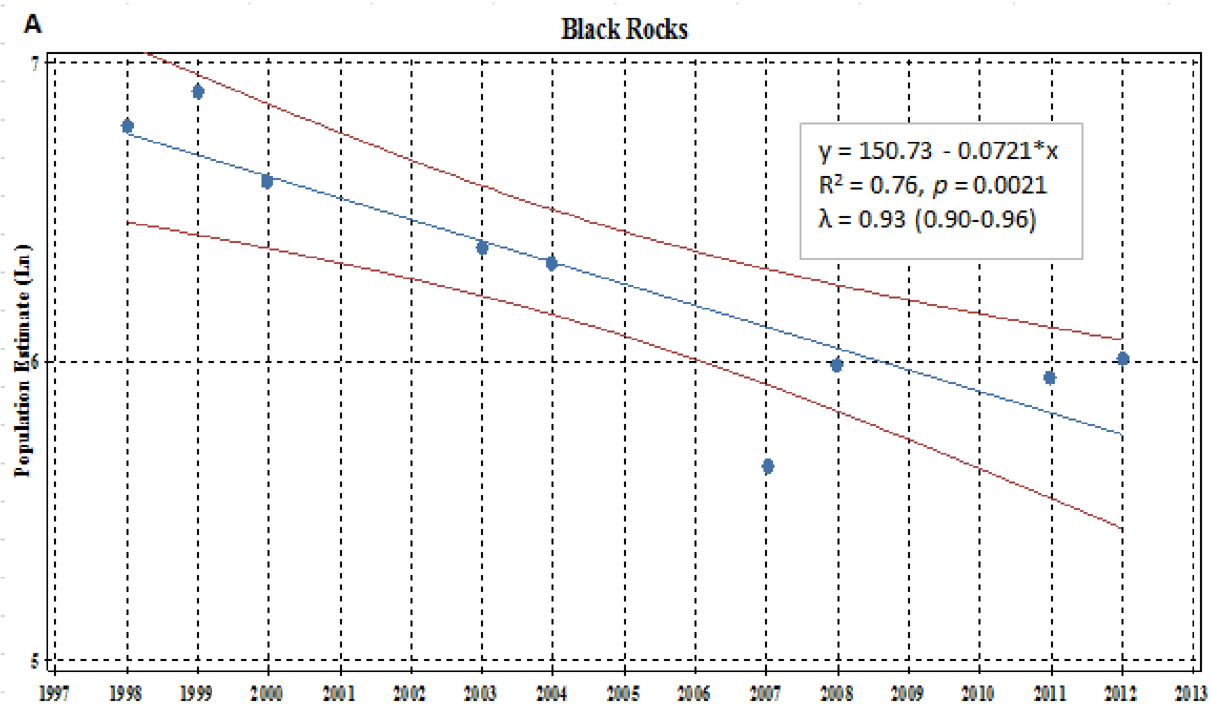

Figure 28. One-phase lambda (λ) for adult Humpback Chub in the Black Rocks population. 95% confidence bounds are shown as bands and computed intervals are presented parenthetically for lambda values.

Survival and Movement—Estimated mean survival rate of adult Humpback Chub remained within a narrow range at 0.64–0.70 for 1998–2011, but differed by size and age; e.g., 0.86 for fish 200 mm TL and 0.69 for fish 400 mm TL (Francis et al. 2016). The decline in adult numbers prior to 2007 is attributed to low adult survival that led to the loss of the larger and presumably more fecund individuals. This also led to reduced reproduction and survival of young, such that recruitment was not keeping up with adult mortality; all brought about by drought and low river flow (see section 5.2.2).

Annual adult abundance has remained relatively stable since 2007, suggesting that recruitment is currently offsetting annual adult mortality, but not to a level that is increasing adult abundance (Francis et al. 2016). Key demographic factors affecting this population are survival and recruitment by young, and survival of the oldest and largest adults to maintain high reproductive potential. A large cohort reported for 2010 is expected to reflect as increased adult numbers for the next scheduled estimates of 2016–2017 (Francis et al. 2016).

Movement of adults between Black Rocks and Westwater Canyon (16 km apart) may be affecting recruitment in the former population, but not the latter. The annual transition of 1.4% of adults from Black Rocks to Westwater Canyon doesn't reflect a measureable change for either population because of the small number of fish. However, the 1.8% annual transition of fish from the larger Westwater Canyon population to the smaller Black Rocks population is measureable (Francis et al. 2016).

Using the 2012 estimates of 404 adults in Black Rocks and 1,315 adults in Westwater Canyon, about six adults could transition annually from Black Rocks to Westwater Canyon for a net increase in adult abundance of 0.5%; but ~24 adults would transition from Westwater Canyon to Black Rocks for a net increase of 5.9%. For Black Rocks, at an annual mortality of 0.30, 121 adults are lost annually to mortality and 6 to transition, but 24 are gained in transition from Westwater Canyon for a net loss of only 103 adults annually. This offsets mortality to 18 adults (121 - 103 = 18) that represents ~22,500 eggs (9 x 2,500 eggs), which could be a significant number of young for the smaller Black Rocks population.

The Black Rocks population has declined since population estimates started in 1998 by ~7% annually. However, the four recent estimates from 2007 to 2012 shows that the number of adults could be stable, but the recent trend is uncertain. The less rigorous, catch-based monitoring dating back to 1988 indicates the population may have been stable over the past 30 years.

5.5.2 Westwater Canyon—The Westwater Canyon population occupies the second smallest geographic area (19.3 km) of the six populations of Humpback Chub. Estimates of adult abundance have ranged from 10,148[10] in 1995 to 1,139 in 2008 (Figure 29A; Table 10). Estimates of adult abundance declined from 1995 to 2000, but appear to have leveled off for the past 16 years. These estimates follow the same pattern as the adult CPUE indices, but also indicate a higher prior population level starting in 1988 (Figure 29B). The latest Recovery Program approved estimate is 1,315 adults in 2012, and the average of 13 estimates is 3,528 adults. A preliminary abundance estimate for Humpback Chub in Westwater Canyon in 2016 is 2,002 adults (Hines 2016), which provides some evidence of a potential population stabilization since 2000. Utah Division of Wildlife conducted another estimate in 2017 for which results will be available in 2018.

[10] The first real commitment to mark / recapture population estimation began in 1998.

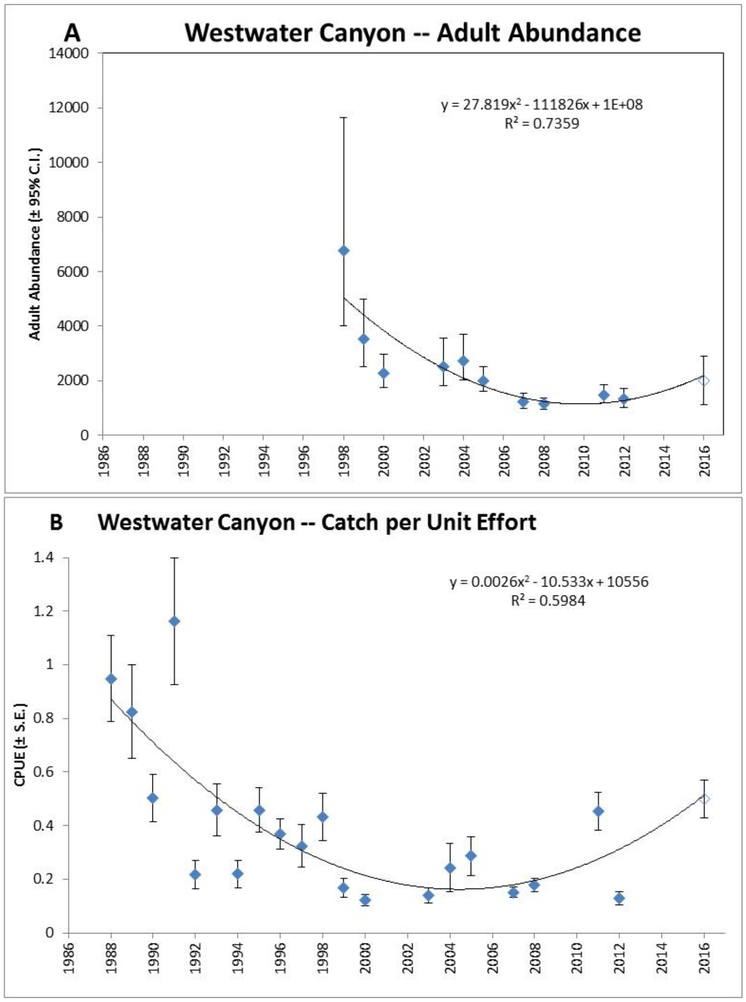

Figure 29. Line of best fit for (A) annual abundance (1994–2012) and (B) trammel net CPUE (1988–2012) of adult Humpback Chub in the Westwater Canyon population. Adult abundance estimates for 1998–2012 from Hines et al. (2016; data for 2016 preliminary). The CPUE data were provided by Brian Hines (UDWR, Pers. Comm. August, 2016).

Population Trajectory and Lambda—A retrospective analysis of the 11 abundance estimates over a period of 18 years (1998–2016) shows that the number of adult Humpback Chub in Westwater Canyon has been in apparent decline, as indicated by a single intrinsic growth rate (λ) of 0.94 (0.89-0.98; Table 11; Figure 30). Since 2007 the declines have potentially been arrested and population estimates are stabilizing,

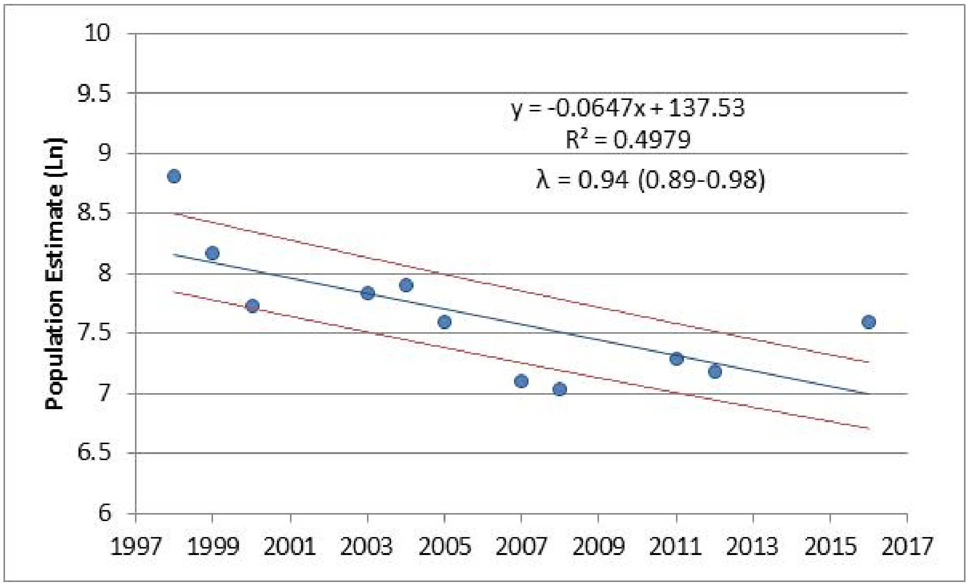

Figure 30. One-phase lambda (λ) for adult Humpback Chub in the Westwater Canyon population. 95% confidence bounds are shown as bands and computed intervals are presented parenthetically for lambda values.

Survival and Movement—Estimated mean survival rate of adult Humpback Chub in Westwater Canyon for 1998-2011 remained in a narrow range of 0.69–0.75, with a mean of 0.70, but differed by size and age; e.g., 0.85 for fish at 200 mm TL and 0.58 for fish at 400 mm TL (Hines et al. 2016). As with the Black Rocks population, the decline in adult numbers is attributed to low adult survival and reduced recruitment, where recruitment was not keeping up with adult mortality caused by natural attrition and low river flow from drought. As with the Black Rocks population, this information indicates that reproduction and survival of young need to be sufficient for recruitment to exceed annual adult mortality, and all these vital rates could be suppressed during periods of drought (see section 5.2.2).

Small numbers of fish move freely between Westwater Canyon and Black Rocks (16 km upstream), such that some have considered these populations as a single core population for the upper basin (e.g., Kaeding et al. 1990; USFWS 2002). The number of fish that leave Westwater Canyon is probably insignificant to adult numbers, as transition rates in and out of Westwater Canyon are relatively low at 1.4% and 1.8%, respectively; this is a net loss of only ~18 adults annually from a population of ~1,315 adults. However, as described for the Black Rocks population, transition of adults from Westwater Canyon to Black Rocks could involve sufficient numbers of individuals to affect adult recruitment when the smaller Black Rocks population is at a low level.

The Westwater and Black Rocks populations are in close proximity and subject to contaminant spills, although recorded spills are rare. On July 24, 1989, a large ash-laden flood entered Westwater Canyon and killed or displaced a large, but unquantified, number of fish (Miles Moretti, Utah Division of Wildlife Resources, Personal Communication, July 1989). The decline in the adult CPUE for 1989 to 1990 may be attributed to this event, but CPUE increased dramatically afterward to its highest level in 1991, indicating that the population recovered from this event and showed high resiliency to catastrophic events.

As with the Black Rocks population, the Westwater Canyon population of Humpback Chub experienced a decline in adult numbers from 1994 to 2007, followed by a period of relative stability with a small increase. Analysis of lengths suggests that the population for 2011–2012 consisted of older fish with few young recruits (Hines et al. 2016). The low number of younger fish could be a result of poor reproduction and survival during recent drought that provided favorable conditions for invasive nonnative fishes and Roundtail Chub. These species likely have a combined carrying capacity and the decline of Humpback Chub may be linked to a high abundance of Roundtail Chub (Hines et al. 2016).

The Westwater Canyon population declined dramatically since reliable population estimates began in 1998, by ~10% annually. However, the four recent estimates from 2007-2016 indicate that the numbers of adults could be stable, but recent trends are uncertain. The less rigorous, catch-based monitoring data set (initiated in 1988) indicates that the population may be experiencing a period of stability, albeit at low densities, which began in 1992 and has continued through the present.

4.5.5.3 Desolation/Gray canyons—The Desolation/Gray canyons population occupies the largest geographic area (113 km) of the five upper basin Humpback Chub populations. Estimates of adult abundance have ranged from 2,856 in 2006 to 1,672 in 2015 (Figure 31A; Table 10, estimates for 2001-2003 are imprecise and were not used in this analysis [Badame 2012]). The average of the five estimates is 2,141 adults. These estimates are too few to make any interpretation of population trajectory, as the data fit is poor to the model of best fit ($R^2 = 0.4129$), and the data do not show a significant slope ($p = 0.5871$). The adult CPUE indices for 1985 to 2015 indicate that adult numbers have been variable, with a possible early decline and more stable numbers from 2006 to 2015 (Figure 31B).

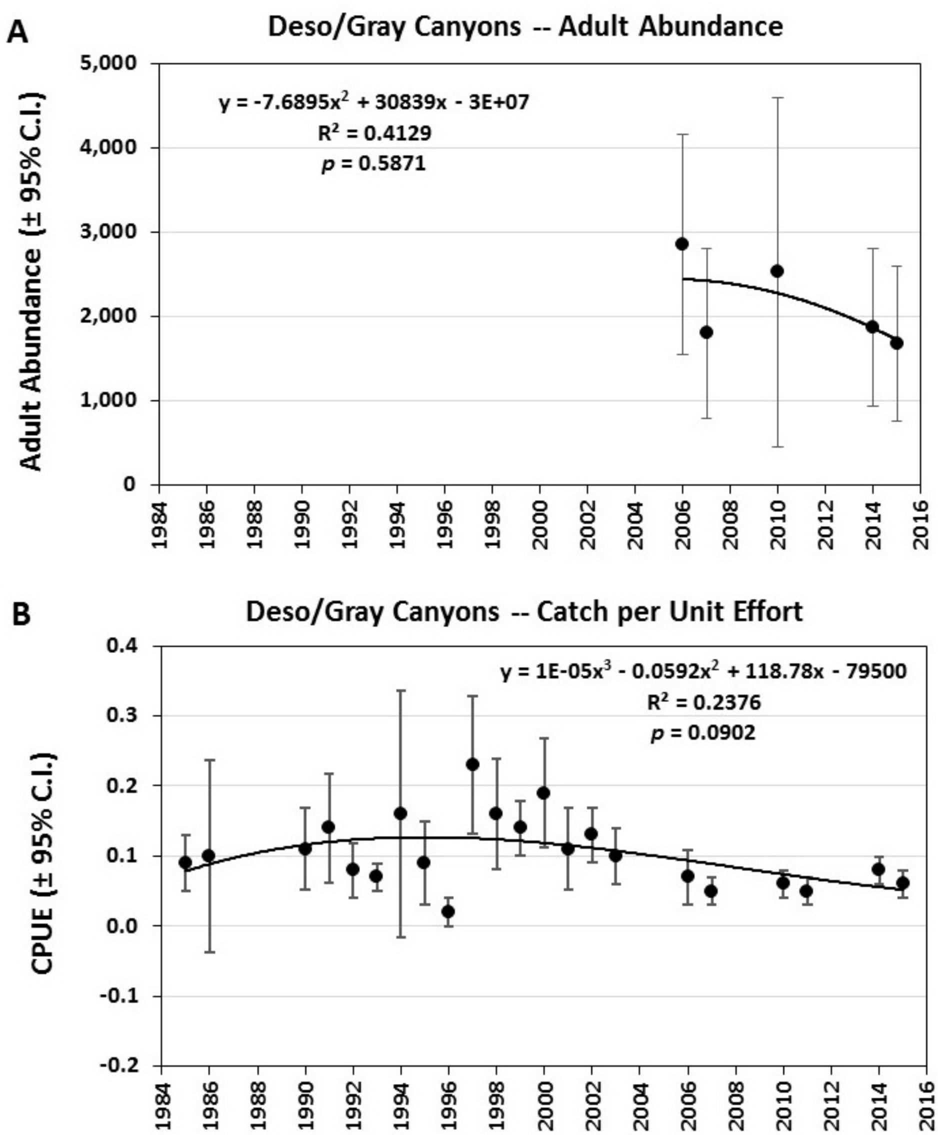

Figure 31. Line of best fit for (A) annual abundance (2006–2015) and (B) trammel net CPUE (1985–2015), of adult Humpback Chub in the Desolation/Gray canyons population. Adult abundance estimates from Howard and Caldwell (2017). The CPUE data were provided by Brian Hines (Utah Division of Wildlife Resources, Personal Communication, August, 2016).

Population Trajectory and Lambda—A retrospective analysis of five abundance estimates over a period of 10 years (2006–2015) shows no apparent reliable pattern for the number of adult Humpback Chub in Desolation/Gray canyons (Figure 32). A one-phase lambda indicates a decline of ~4% per year (λ = 0.96 [0.91-1.01]), but the number of estimates is too small and variable to reach any reliable conclusion for population trajectory.

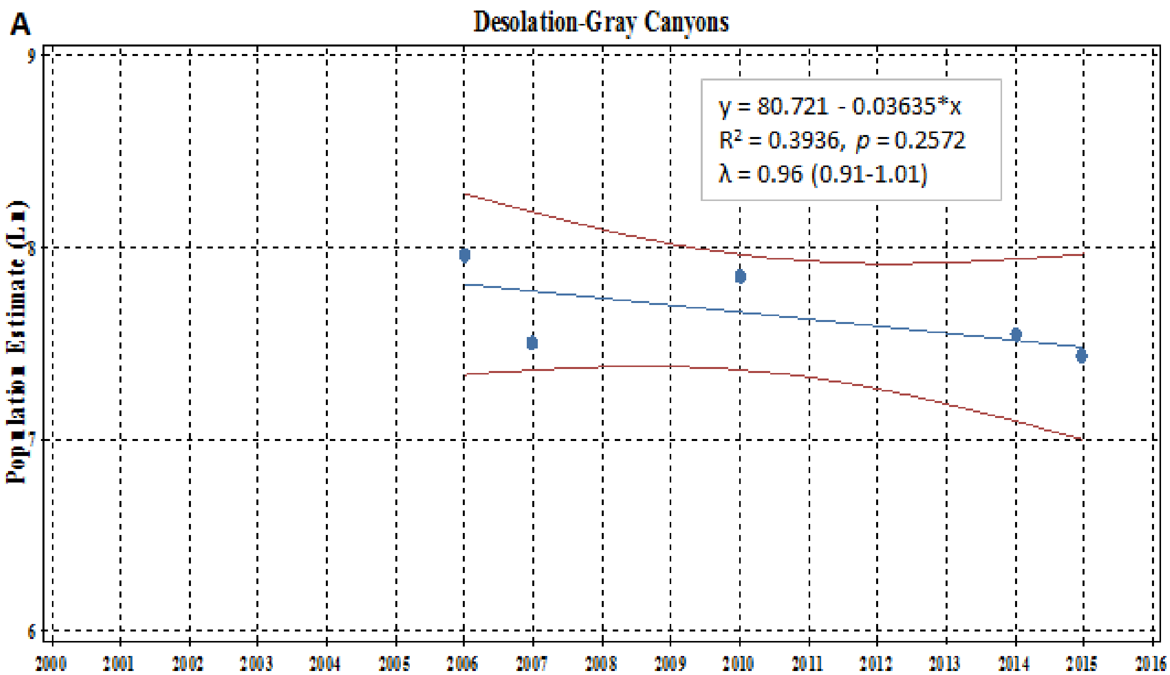

Figure 32. One-phase lambda (λ) for adult Humpback Chub in the Desolation/Gray canyons population. 95% confidence bounds are shown as bands and computed intervals are presented parenthetically for lambda values.

Survival and Movement—Estimated mean survival of adult Humpback Chub in Desolation/Gray canyons for 2001–2015 ranged from 0.53–0.69, which is lower than adult survival in Black Rocks (0.64–0.70; Francis et al. 2016) and Westwater Canyon (0.69–0.75; Hines et al. 2016). Lower survival in Desolation/Gray canyons may be due to the large numbers of Channel Catfish and recent invasions of Smallmouth Bass and Walleye that are either absent or present in low numbers in other populations (Howard and Caldwell 2017). These predators may be sufficiently large to consume sub-adult and small-bodied adult Humpback Chub of this population.

Nonnative fish predation is a particular problem in the Desolation/Gray canyons population. Smallmouth Bass, first captured in this area in 2001 (Jackson and Hudson 2005), have increased in number and in 2004 large-scale removal was implemented in the Green and Yampa rivers, including Desolation/Gray canyons. Although Smallmouth Bass densities have declined by as much as 50%, their distribution has expanded and a decline of Humpback Chub in the upper 72 km of Desolation Canyon correlates strongly with the appearance and persistence of this predator (Badame et al. 2013).

Recruitment in the Desolation/Gray canyons population is not known, as with the other populations in the upper basin. The proportions of first-year adults to older adults in the population has been suggested by Howard and Caldwell (2017) as one index of recruitment, but fish cannot be confidently classified as Humpback Chub from morphological examination.

Little exchange of individual Humpback Chub occurs between Desolation/Gray canyons and the other populations to enhance recruitment. This population is ~257 km downstream from Yampa Canyon and ~217 km upstream from Cataract Canyon, and very little movement of individuals from other populations has been documented (see section 4.1.6).

The Desolation/Gray canyons population has been subject to several catastrophic events. Large floods laden with debris and ash have entered Desolation Canyon following range fires. Also, a ruptured well released oil into the Green River upstream of this area in 2014. These events took place when river volume was low and there was little dilution of the debris and ash that suffocated fish, although the number of dead fish was not documented. The population appears to have recovered from these events, and as with other populations, the species shows high resiliency to these catastrophic events.

The demographic evidence is insufficient to reach any reliable conclusion about the past or present trajectory of the Desolation/Gray canyons population of Humpback Chub. Estimates of abundance indicate that the number of adults is between ~1,500 and 3,000, and that numbers may be in a recent decline. Additional estimates, scheduled for 2018 and 2019, are needed to provide a better understanding of the trajectory of this population. The less rigorous, catch-based monitoring starting in 1985 serves as the basis for our contention that this population has demonstrated stability over the past 30+ years.

4.5.5.4 Cataract Canyon—The Cataract Canyon population is the second smallest population of Humpback Chub (the DNM population is smaller). Only three estimates of adult abundance are available for the Cataract Canyon population; 468 in 2003, 273 in 2004, and 295 in 2005 (Figure 33A; Table 10). The average of the three estimates is 345 adults. Abundance estimates are too few to show a pattern.

Fourteen adult CPUE indices are available from Cataract Canyon for trammel nets catches over a period of 25 years (1991–2015; Figure 33B). These indices show a variable, but persistent population with no significant increase or decrease for the period of sampling (p = 0.5984). The more recent catch rates, since 2003, indicate a higher number of adults than prior estimates, but the data are too variable and are a poor fit to the model of best fit (R^2 = 0.0891).

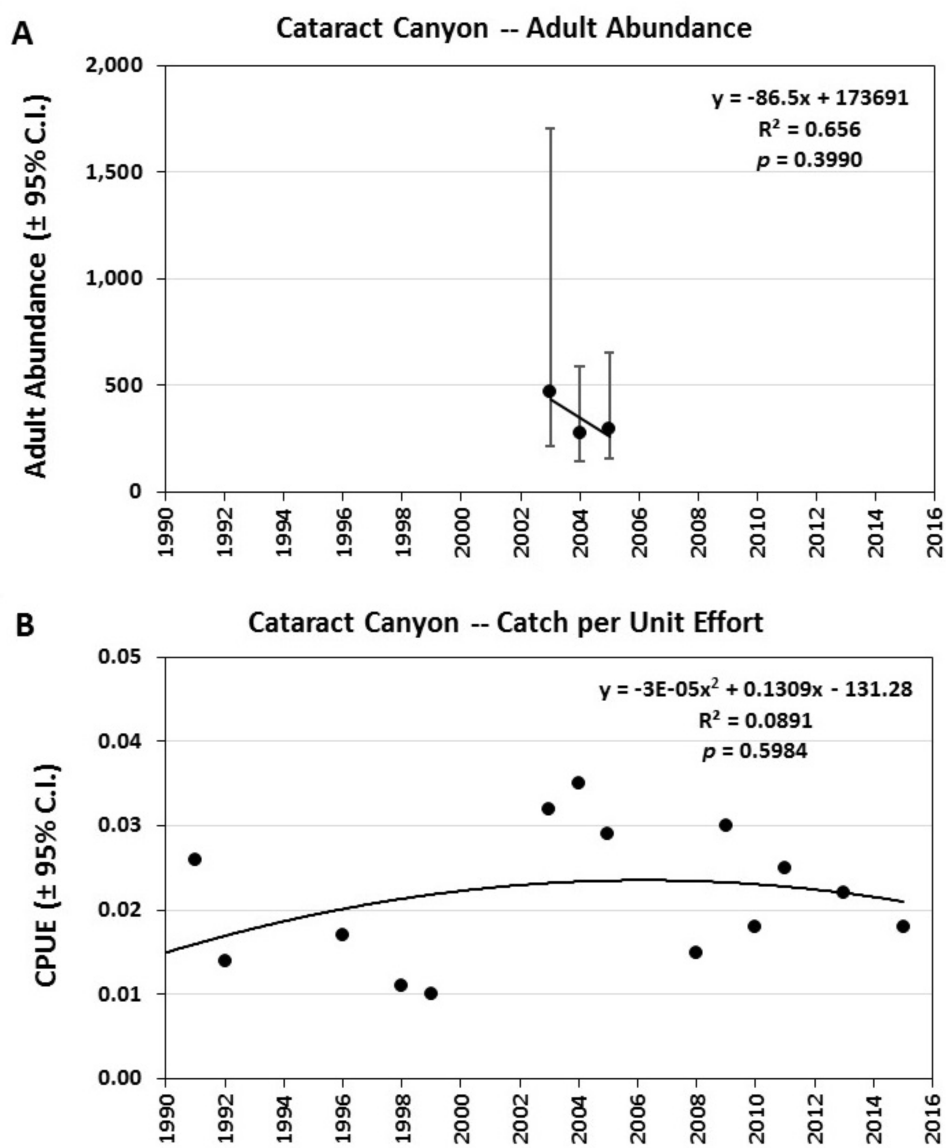

Figure 33.Line of best fit for (A) annual abundance (2003–2005) and (B) trammel net CPUE (1991–2014) of adult Humpback Chub in the Cataract Canyon population. Adult abundance estimates and CPUE data from Badame (2008) and Ahrens (2015).

Population Demography—This population is a remnant of the Humpback Chub population that probably extended the full length of Cataract Canyon for a distance of ~56 km from the confluence of the Green and Colorado rivers downstream to Sheep Canyon. The lower 19 km of Cataract Canyon was inundated by Lake Powell in the early 1980s, but recent receding reservoir levels are exposing historical habitat that could allow for a downstream expansion of this population—as has been seen in western Grand Canyon with receding levels of Lake Mead.

The number of fish captured in Cataract Canyon has remained low for the last 25 years, but the area is difficult to sample and only gears used to catch large fish (trammel nets) are generally used (Table 12; Valdez et al. 1982; Valdez 1990; Badame 2008). Efforts to capture younger life stages with seines, minnow traps, and fyke nets have yielded a few fish, but the size and age composition of the population is unknown.

Table 12. Numbers of Humpback Chub by life stage captured in Cataract Canyon. "--" indicates that gear types were not used to sample a particular life stage of fish.

Year[a]	Larvae	Young-of-Year	Juvenile	Adult	Total
1980	--	--	--	1	1
1985	0	7	1	2	10
1986	8	4	2	3	17
1987	0	4	11	6	21
1988	2	4	42	11	59
1991	--	--	--	36	36
1992	--	--	--	19	19
1996	--	--	--	23	23
1998	--	--	--	15	15
1999	--	--	--	14	14
2003	--	--	--	44	44
2004	--	--	--	43	43
2005	--	--	--	31	31
Total	10	19	56	248	333

[a]1980 from Valdez et al. (1982); 1985-1988 from Valdez (1990); 1991-2005 from Badame (2008)

Observers in the field have noted that Humpback Chub in Cataract Canyon are smaller in body size than fish from other populations (e.g., Valdez 1990, Badame 2008). Meretsky et al. (2000) quantified this observation by comparing length-weight relationships for adults in primary populations during the early to mid-1990's, and showed that adults in Cataract Canyon were smallest and had the lowest condition of any population. Badame (2008) found length weight relationships for 2003-2005 that were nearly identical to those reported by Meretsky et al. (2000), and suggested that small size and low condition may be inherent traits of the Cataract Canyon population and reflective of the extreme hydraulic condition found in the deep, swift waters of the canyon.

An absence of adults over 300 mm TL in Cataract Canyon suggests a lower reproductive potential and may help to explain the small population size. Apparent annual growth rates of individual Humpback Chub in Cataract Canyon are also slower than those reported for all other upper basin populations (Valdez 1995; Meretsky et al. 2000; Jackson and Hudson 2005). This lack of later life stage growth creates a narrow unimodal size distribution for fish over 200 mm TL. Badame (2008) found that this phenomenon intensified over the 2003–2005 period, when all presumed adults captured fell within a size range of ~60 mm.

The Cataract Canyon population is located immediately downstream of the confluence of the Upper Colorado and Green rivers, and thus, occupies an area with the highest contemporary spring peak flow of the six populations. Spring flow is commonly over 50,000 cfs and approached 100,000 cfs each in 1983 and 1984. This hydrologic regime provides a constantly turbulent habitat laden with debris and sediment that may suppress fish size and growth, but provides a reliable food source and greater security and protection than other populations subject to lower flow.

The Cataract Canyon population has not been subject to any known catastrophic events, and is a long distance downstream from other populations; e.g., ~190 km downstream from the Westwater Canyon population of the upper Colorado River and ~217 km downstream from the Desolation/Gray canyons population of the Green River. With no perennial tributaries in Cataract Canyon and a great distance to other populations, there is a low probability for exchange of individuals with other populations. Historical connection with the Grand Canyon population may be possible, but the Cataract Canyon population currently remains largely isolated (Badame 2008), except for an occasional fish moving upstream to the Green River and Desolation/Gray canyons (see section 4.1.6). Demographic data are insufficient to conduct a retrospective lambda analysis of the Cataract Canyon population.

Humpback Chub have been consistently caught in Cataract Canyon during periodic sampling since 1980, albeit in small numbers, and young life stages are found when the appropriate sampling gear is deployed. Based on this information, it appears that the population is small but persisting; the trajectory of adult numbers is unclear.

4.5.5.5 Dinosaur National Monument—The DNM population is the smallest of the six populations, with any fish remaining being below detection limits. Estimates range from 320 adults in 2001 to 224 adults in 2003 (Figure 34; Table 10), but the low number of individuals in recent years has precluded additional estimates. Only three Humpback Chub were caught in Whirlpool Canyon in 2003 and two and eight in Yampa Canyon in 2003 and 2004, respectively (Finney 2006). The last humpback chub was captured in Whirlpool Canyon in 2006 (Bestgen & Irving 2006). The number of Humpback Chub in Yampa Canyon is small with no fish captured recently (Jones 2012, 2013, 2014).

The historical distribution and abundance of the Humpback Chub population in DNM is not well known, and it is unclear if substantial numbers of fish were ever present in this area. In the 1940s, Humpback Chub were found in the lower Yampa River and in Whirlpool Canyon (Tyus 1998). Holden (1973) reported catching 26 "humped chubs" near Echo Park in 1969. By 1987–1989, only two Humpback Chub were caught in upper Whirlpool Canyon, none in Lodore Canyon, and 131 in Yampa Canyon (Karp and Tyus 1990). For the purpose of this assessment, it is assumed that a population once extended from the lower Yampa River into the Green River and downstream through Echo Park, and Whirlpool Canyon, based on the persistence of apparent suitable habitat and a few available historic records of collected specimens, as previously described.

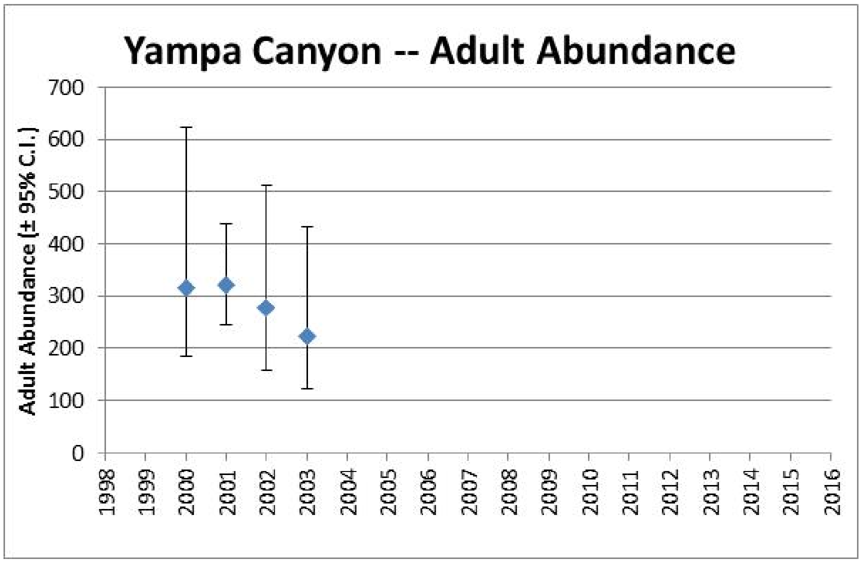

Figure 34. Line of best fit for annual abundance (2000–2003) of adult Humpback Chub in the Yampa Canyon population. Estimates from Haines and Modde (2002) and Finney (2006).

The Humpback Chub is now rare in Whirlpool Canyon, with a few fish remaining in the lower Yampa River. It appears that the fish in the Green River were negatively affected by the cold releases from Flaming Gorge Dam starting in 1963, and the fish in the Yampa River were negatively affected by low river flows and a simultaneous expansion of Smallmouth Bass starting in ~2000. Despite this apparent decline in the number of Humpback Chub in DNM, the geomorphic framework and general habitat do not appear to have changed appreciably, other than the effect of nonnative fish and low flow from drought. A temperature control device on Flaming Gorge Dam has warmed the Green River, and an ongoing nonnative fish control program is reducing the abundance of Smallmouth Bass. The habitat is otherwise suitable, but immigration from other populations is too low for the population to rebuild naturally. Intervention (e.g., translocation or stocking) will be necessary to restore numbers of fish to the area to restart the population.

A genetic analysis of Humpback Chub from Yampa Canyon was inconclusive as to the distinctness of the fish (Douglas and Douglas 2007), suggesting that introgressive hybridization had been occurring in that population for some time, as reported by Tyus (1998). In 2007, ~400 juvenile *Gila* spp. were removed from Yampa Canyon and transferred to two hatchery facilities to establish a refuge population. The fish were grown to identifiable size and no fish with Humpback Chub morphology or genetics were found; all fish had the same genetic makeup as the Roundtail Chub of the same population (Bohn 2016). This collection of fish confirmed that the number of Humpback Chub remaining in Yampa Canyon is quite low. Recent sampling in Whirlpool Canyon of the adjacent Green River showed that the number of Humpback Chub in this canyon is also low (Bestgen & Irving 2006).

It appears that the cause of decline for the DNM population is a combination of factors linked to effects in two river systems. Fish numbers in Whirlpool Canyon apparently declined because of cold water temperature in the Green River following construction of Flaming Gorge Dam in 1962 and the invasion of various nonnative fish predators and competitors. The decline of Humpback Chub in the Yampa River (a largely unregulated river) was apparently caused by unusually low natural flow and a corresponding expansion of predaceous Smallmouth Bass in 2000. The number of Roundtail Chub also expanded at this time, increasing competition and the likelihood of hybridization. The Yampa River near Maybell, CO, has an average flow of ~368 cfs (USGS 09251000, 1916-2015), but on August 31, 2002, the flow dropped to 1.8 cfs, which was the lowest recorded flow in 100 years. This period of low flow allowed for expansion of the already present Smallmouth Bass and Roundtail Chub (Haines et al. 2006).

The population of Humpback Chub in DNM may have historically functioned somewhat like the population in the Grand Canyon, where a large portion of fish reside in the mainstem Colorado River and move annually to spawn and rear in the smaller, seasonally-warmed LCR. The juxtaposition of Echo Park and Whirlpool Canyon on the Green River and the lower Yampa River may be an analogue to the situation in the Grand Canyon. The setting in the lower Yampa River and adjacent Green River may provide a framework for restoring this population, where the fish would reside primarily in the Green River and ascended the Yampa River for spawning and rearing.

Dinosaur National Monument is a long distance from the other Humpback Chub populations, and it is very unlikely that natural demographic rescue from large-scale immigration will occur. The mouth of the Yampa River is ~257 km upstream from the Desolation/Gray canyons population, and movement of significant numbers of fish from that population is not likely (see section 4.1.6). Restoring the DNM population will require specific management actions, such as translocation or stocking of fish into Whirlpool and Yampa canyons.

Successful translocations of Humpback Chub in the Grand Canyon have demonstrated the ability of the species to adjust to being displaced to new locales. This strategy of moving wild juveniles from one population to new or historical habitat may be possible for restoring the DNM population. Alternatively, a broodstock of upper basin fish has been recommended (Bohn and Wilson 2017) for hatchery production of fish to be stocked into historical habitat.

The Dinosaur National Monument population is currently below detection limits and is now considered functionally extirpated. Because immigration of Humpback Chub into this population is low, the probability of natural rescue effects is low and intervention in the form of translocations or hatchery stocking will be necessary to restore numbers to the area.

4.5.6 Grand Canyon—The Grand Canyon population is the largest and most extensively distributed population of Humpback Chub. It exists as a core population in the lower 18 km of the LCR, as well as ~406 km of the mainstem Colorado River from RM 30 to RM 282, as well as a translocated population in the lower 6 km of Havasu Creek. The estimated number of adults in the LCR core population has ranged from a high of 10,948 in 1989 to a low of 5,021 in 2001, and 7,650 in 2008 (Figure 35; Table 14; Coggins and Walters 2009). The average of 20 estimates for 1989–2008 is 7,080 adults.

More recent estimates for 2009–2012 indicate that the population has remained stable (Yackulic et al. 2014). The number of adults in the mainstem has apparently increased from ~250 in nine aggregations in 1995 (Valdez and Ryel 1995) to a much larger number, as indicated by the number of fish captured, especially in western Grand Canyon (Rogowski et al. 2017). The number of young has also increased in the mainstem with recent catches showing a cross-section of sizes and apparent ages that indicate successful mainstem reproduction (Kegerries et al. 2016; Rogowski et al. 2017).

Cause for the decline in adult numbers from 1989 to 2001 is unclear, but recruitment reconstructions suggest a peak in recruitment in the late 1970s to early 1980s of 13,500–18,500 age-2 fish annually, which led to the recorded peak in adult abundance in 1989 (Coggins 2008). After that peak, an overall decline was evident to the early 1990s, when annual recruitment stabilized at ~2,000 age-2 fish annually. This increase appears to be related to an increasing recruitment trend beginning perhaps as early as 1996, which corresponds to a new EIS and a change in dam operations to modified low fluctuating flows (Bureau of Reclamation 1996).

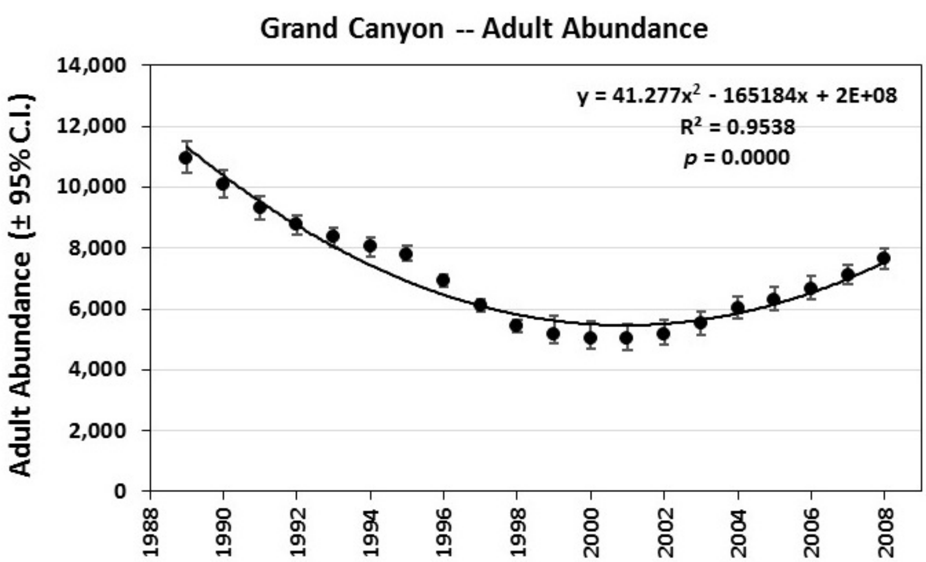

Figure 35. Estimated adult abundance of Humpback Chub (≥ 200 mm TL) for 1989–2008 in the LCR population from an Age Structured Mark-Recapture Model (ASMR; Coggins and Walters 2009).

Table 13. Estimated annual abundance of adult Humpback Chub (age 4+, ≥ 200 mm TL) for 1989–2008 in the LCR population from an Age Structured Mark-Recapture Model (ASMR; Coggins and Walters 2009). N = population estimate, Low CI = lower 95% confidence interval, High CI = upper 95% confidence interval.

Year	N	Low CI	High CI
1989	10,946	10,494	11,519
1990	10,111	9,660	10,544
1991	9,342	8,941	9,699
1992	8,766	8,424	9,070
1993	8,368	8,058	8,683
1994	8,045	7,739	8,332
1995	7,808	7,571	8,064
1996	6,945	6,711	7,150
1997	6,118	5,907	6,342
1998	5,432	5,227	5,622
1999	5,164	4,856	5,795
2000	5,048	4,680	5,616
2001	5,021	4,656	5,516
2002	5,185	4,820	5,633
2003	5,530	5,165	5,925
2004	6,020	5,685	6,423
2005	6,301	5,957	6,713
2006	6,673	6,318	7,095
2007	7,123	6,820	7,445
2008	7,650	7,335	8,009

Population Trajectory and Lambda—A retrospective analysis of 20 abundance estimates over 20 years (1989–2008) shows that the number of adult Humpback Chub in the LCR core population of Grand Canyon underwent a decline to the year 2001, and a subsequent increase to 2008 (Figure 36). The ASMR Age-Structured Mark-Recapture model results (used from 1989-2008) are likely negatively biased because it does not account for temporary emigration (skip-spawning), potentially underestimating abundances up to 20-30% in population estimates (Yackulic, personal communication, November 2017). More recent estimates, using a multi-state model that accounts for temporary emigration, show adult numbers at 11,500–12,000 (Appendix S3 of Yackulic et al. 2014), indicating that the population has remained relatively stable since 2008.

The pattern in adult numbers shows a clear change in trajectory after 2001, and a two-phase lambda of 0.93 (0.92-0.94) indicates that numbers declined at a rate of 7% per year in the first 13 years, followed by a lambda of 1.06 indicating that numbers increased at a rate of 6% per year in the subsequent 7 years (Figure 36B). The two-phased lambda is supported by the AIC_c calculated in Table 11. This analysis shows that despite a substantial decline in adult numbers over a period of what could have been a generation time (16 years, see section 5.1), the number of adults has probably recovered—or surpassed the level of nearly 11,000 seen in the initial census of 1989 with the 2012 estimate of 12,000.

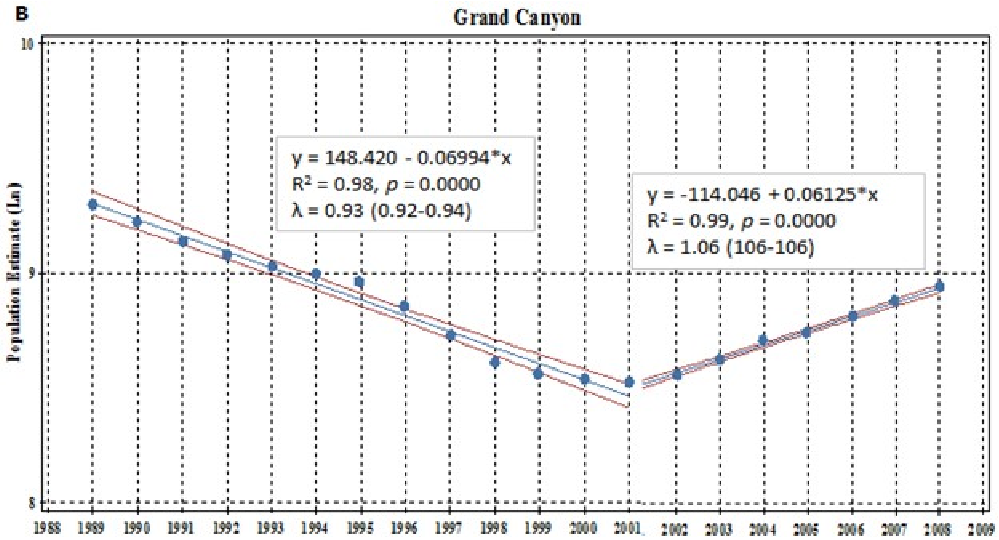

Figure 36. Two-phase lambda (λ) for adult Humpback Chub in the Grand Canyon population. 95% confidence bounds are shown as bands and computed intervals are presented parenthetically for lambda values.

Survival and Movement—The earliest estimated annual survival of mainstem Grand Canyon adults, based on mark-recapture data and open population models, was 0.755 (95% C.I. = 0.627–0.896; Valdez and Ryel 1995). Coggins and Walters (2009) determined that a natural mortality rate of 0.13 (survival rate = 0.87) provided the best solution for an individual-based simulation model (IBM) for adult Humpback Chub associated with the LCR. A more recent analysis shows survival of fish in the two systems is complicated by temperature. Humpback Chub that rear in the cold mainstem live ~5 times longer than fish in the seasonally-warmed LCR, but may take more than twice as long to reach adulthood and are ~40% less likely to survive to adults (Yackulic et al. 2014).

The survival estimates of 0.76–0.87 are considerably higher than survival for populations in Desolation/Gray canyons (0.53–0.69; Howard and Caldwell 2017), Black Rocks (0.64–0.70; Francis et al. 2016), and Westwater Canyon (0.69–0.75; Hines et al. 2016). The reason for different adult survival among populations is not clear, but is likely related to a number of factors, including habitat condition, food supply, river flow, predation, and competition. This may also be linked to the fact that Grand Canyon fish spawn in the less stressful environment of the LCR and return to the cold mainstem that aids recovery from spawning.

The demography of the Humpback Chub in the Grand Canyon is better understood than for the upper basin populations. This is largely because the core population is centered in the

LCR, where a large portion of the population can be sampled annually during spring spawning. Annual sampling has produced a robust data set that has been used to generate reliable estimates of survival, recruitment, and abundance (e.g., Coggins et al. 2006; Coggins and Walters 2009; Van Haverbeke et al. 2013; Yackulic et al. 2014).

Distribution—Initial surveys of Humpback Chub in the Grand Canyon characterized their distribution in the mainstem as nine aggregations, or small groups of fish with little evidence of reproduction. In 1995, the estimated number of adults in these aggregations ranged from 5 at Pumpkin Springs to 98 in Middle Granite Gorge (Valdez and Ryel 1995). Subsequent surveys by Persons et al. (2015) consolidated these aggregations into six (Table 14).

Table 14. Locations of six mainstem Humpback Chub aggregations in Grand Canyon, including river mile boundaries, estimated number of adults (N), and 95% confidence intervals (C.I.) estimated by Valdez and Ryel (1995). Redefined aggregation boundaries are described by Persons et al. (2015).

Aggregation	Aggregation Boundaries (RM)	Redefined Boundaries (RM)	N	95% C.I.
30-Mile	29.8–31.3	29.8–36.3	52	24–136
LCR inflow	57.0–65.4	57.0–77.2	3,482	2,682–4,281
Shinumo Creek inflow	108.1–108.6	107.8–110	57	31–149
Middle Granite Gorge	126.1–129.0	125.0–129.7	98	74–153
Havasu Creek inflow	155.8–156.7	155.8–159.2	13	5–70
Pumpkin Spring	212.5–213.2	212.5–216.0	5	4–16

An increasing number of Humpback Chub of all ages has been found in the mainstem in the last decade, possibly because of warmer dam releases starting in 2004 and expanding habitat in western Grand Canyon with the receding level of Lake Mead. In 2006, 739 age-0 Humpback Chub (13–66 mm TL) were captured in backwaters between Lees Ferry (RM 0) and Diamond Creek (RM 226) (Ackerman 2008). Many were captured at locations that correspond to known aggregations, but captures have become increasingly frequent throughout the mainstem, blurring the boundaries of the aggregations, and serving as evidence of mainstem reproduction. In 2014 and 2015, larvae and juveniles were found in western Grand Canyon (Kegerries et al. 2016), and a system-wide survey by AGFD in 2016 found 319 Humpback Chub (58–433 mm TL) between Lees Ferry (RM 0) and Pearce Ferry (RM 281) (Figure 37; Rogowski et al. 2017). These findings expanded the distribution of the species by ~108 km downstream (from Pumpkin Spring at RM 213 to Pearce Ferry at RM 282); the expansion is attributed to the lower elevation of Lake Mead exposing historical habitat starting in ~2002 beginning at RM 235 (Bridge Canyon), and possibly warmer dam releases starting in 2004.

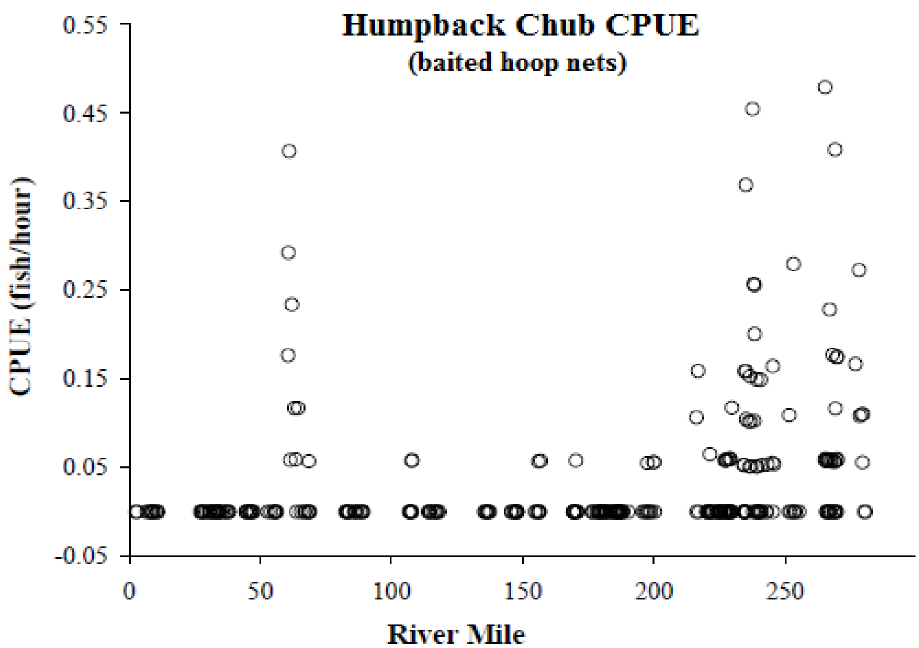

Figure 37. Humpback Chub mean catch per unit effort (CPUE; fish/hour) for baited hoop nets by river mile in 2016 (n = 319). Source: Rogowski et al. (2017).

Fish found recently in western Grand Canyon may have originated from spawning in the mainstem or in tributaries such as Havasu Creek. Evidence of reproduction by translocated Humpback Chub was found in Havasu Creek in 2012-2017; ripe spawning males were captured in May 2012, and ripe males and females, as well as untagged juveniles were captured in May 2013 (Nelson et al. 2016; Personal communication Brian Healy, 2017). Also, 12 ripe males were captured in the mainstem Colorado River upstream of the mouth of Shinumo Creek in June 2015 (Healy et al. 2014a). Some Humpback Chub translocated to Shinumo and Havasu creeks have descended to the mainstem, where greater numbers of ripe fish are being found. A small amount of reproduction has also taken place with translocated fish upstream of natural falls 14 km up the LCR (Stone 2016). These positive responses by wild and translocated Humpback Chub in the Grand Canyon are signs of an expanding and increasing population as the result of active management (translocations of fish), as well as climate-related phenomena (warmer dam releases and receding lake levels).

Translocations—Since 2003, young Humpback Chub have been translocated from the LCR to tributaries in the Grand Canyon above chutes and waterfalls. These translocations followed an implementation plan in 2000 developed for establishing a second population of Humpback Chub in the Grand Canyon (Valdez et al. 2000). The plan identified establishing populations of Humpback Chub in one or more tributaries of the Grand Canyon, and in 2003, fish were translocated from the lower LCR to the LCR above Chute Falls (RK 16.2) for the purpose of expanding the population upstream into unoccupied habitat and to develop methods for translocating live fish. For the period 2003–2015, a total of 2,971 juvenile

Humpback Chub was translocated by the U.S. Fish and Wildlife Service to the LCR above Chute Falls (Table 16; Stone 2016).

Table 15. Numbers of Humpback Chub translocated from the LCR to tributaries in the Grand Canyon. All fish were captured as juveniles (~50–140 mm TL) from the LCR, held at the Southwestern Native Aquatic Resources and Recovery Center (SNARRC) in New Mexico for ~6 months, where they were treated for parasites and diseases, and then they were released in May or June. All fish were PIT tagged prior to release, except for the 1,150 fish in the LCR Upper Reach that were VIE-tagged in 2003–2005.

Year of Release	Shinumo Creek[a]	Havasu Creek[b]	LCR Above Chute Falls (RK 16.2)[c]
2003	--	--	283
2004	--	--	300
2005	--	--	567
2006	--	--	--
2007	--	--	--
2008	--	--	299
2009	300	--	194
2010	300	--	109
2011	300	243	96
2012	0	298	212
2013	200	300	303
2014	0	300	305
2014[d]	--	209	--
2015	--	300	303
Totals:	**1,100**	**1,650**	**2,971**

[a] Data from Healy et al. (2014a)
[b] Data from Nelson et al. (2016)
[c] All fish translocated to the LCR were released at RK 16.2, which is 2.2 km above Chute Falls (Data provided by D. Stone, U.S. Fish and Wildlife Service, August 1, 2016)
[d] The June 2014 translocation to Havasu Creek was done in lieu of a translocation to Shinumo Creek due to anticipated negative impacts from the Galahad Fire. In July and August 2014, large floods and a debris flow followed the fire and killed or displaced all fish in Shinumo Creek (Healy et al. 2014c)

The translocation of fish in the LCR was successful, and in 2009, the National Park Service (NPS) began translocating juvenile Humpback Chub from the LCR to Shinumo Creek that totaled ~1,100 fish by the year 2013 (Table 15; Healy et al. 2014a). Many fish survived and became residents of Shinumo Creek and some descended and augmented the mainstem aggregation; Spurgeon et al. (2015) found that at least 53% of translocated juvenile Humpback Chub left Shinumo (35% left within the first 25 days of translocation). But, in 2014, a series of large ash-laden floods and a debris flow followed a wildfire in the drainage and killed or displaced the fish to the mainstem, eliminating all Humpback Chub from this tributary (Healy et al. 2014c).

In 2011, the NPS also translocated juvenile Humpback Chub into Havasu Creek for a total of 1,650 by the year 2015 (Table 15). Many of these fish have survived and have a high growth rate similar to that of fish in the LCR. Evidence of reproduction is also found in Havasu Creek. Ten untagged fish less than 150 mm TL and 15 fish ranging in size from 150-210 were captured in October 2015, indicating that natural spawning is taking place in Havasu Creek (Nelson et al. 2016), and recruitment to maturity has been documented through October of 2016. The latest population estimate for Humpback Chub ≥ 150 mm TL in Havasu Creek in May, 2016 was 297 (95% C.I. 291 – 327) (Brian Healy, National Park Service, Personal Communication, September 2017). A second population in the mainstem, or in a second tributary (as with the LCR) would bring greater levels of resiliency and redundancy to this population of Humpback Chub.

The Grand Canyon population of Humpback Chub is self-sustained with a large core population and multiple dispersed aggregations, with additional evidence of expansion from warmer dam releases, exposed historical habitat, and recent translocations of fish to tributaries.

4.5.7 Sum of Adult Numbers—Altogether, there are ~16,050 adult Humpback Chub in the entire Colorado River System, as of the last comprehensive census of 2012 (Figure 38). This includes ~3,800 adults in the upper basin[11], or 24% of the total, and ~12,250 in the lower basin, or 76% of the total. There are also several thousand young in each population that vary annually in number depending on reproductive success and survival. Using the most recent population estimate for each population (with varying dates), the largest numbers of adults are in the Grand Canyon population (12,250), followed by Desolation/Gray canyons (1,672), Westwater Canyon (1,315), Black Rocks (404), Cataract Canyon (300), and DNM (Yampa River with a small number of individuals remaining).

The abundance of adults in populations of the upper basin, including Black Rocks, Westwater Canyon, and Desolation/Gray canyons has followed a similar pattern in which numbers were highest in 1998–2000 and declined to low but stable numbers starting in ~2007. In contrast, the number of adults in the Grand Canyon was lowest in 2001 and has continued to increase through 2012.

[11] Since 2007, mean sum of adults in the three upper basin populations with robust estimates is about 3,800, which is a period of apparent stability. The remaining two populations do not have recent robust estimates.

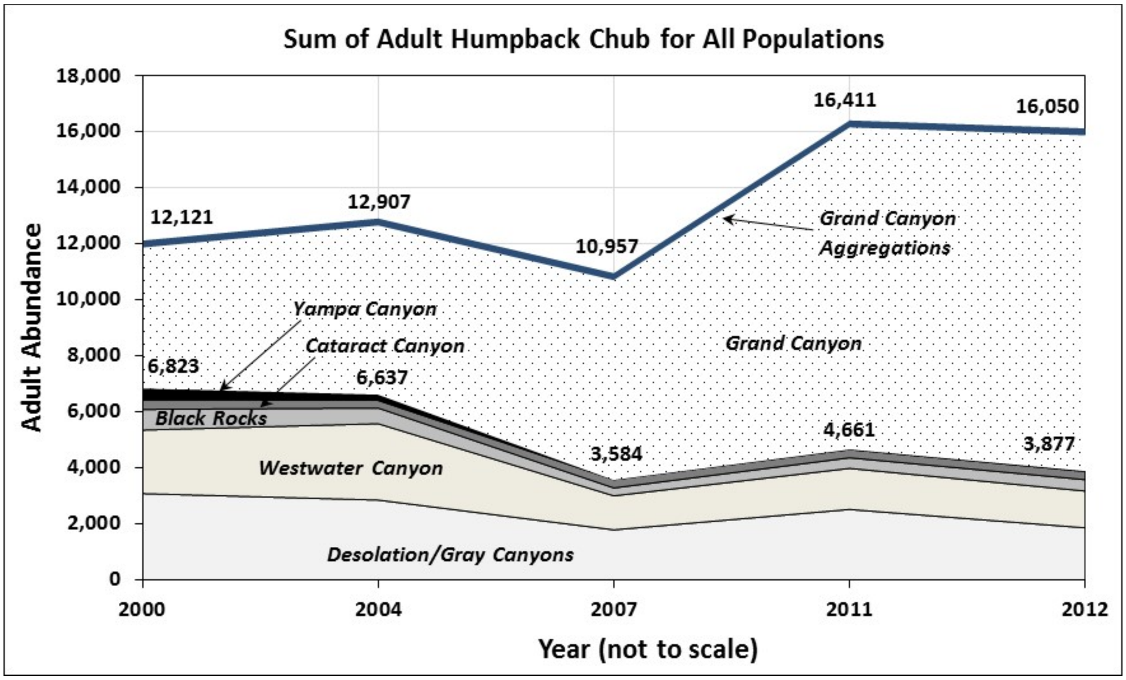

Figure 38. Cumulative sum of adult Humpback Chub for all populations in the census year. Estimates of adult abundance in the upper basin are not done every year, and values from the nearest year were used where estimates were not available. Note: dramatic increase in Grand Canyon populations may be misleading as estimates from 2000-2008 used an ASMR model which may be negatively biased.

5.0 FUTURE CONDITION

The assessment of current condition determined that stream flow and predation/competition are the key factors controlling upper basin populations; whereas, stream flow, water temperature, food supply, and predation/competition are the key factors for the lower basin population. Narratives in this section describe the probable future condition for these factors in the upper basin and lower basin. Section 5.1 defines a "biologically meaningful time frame" to place context on the span of time into which it is feasible to project future condition. Section 5.2 describes the risks and uncertainties in describing redundancy, resiliency, and representation for a biologically meaningful time frame. Section 5.3 describes the future condition of populations under three possible future scenarios that incorporate the uncertainty of the future, and this information is summarized in Tables 17, 18 and 19.

5.1 Biologically Meaningful Time Frame

The concept of a "biologically meaningful time frame" is used in this SSA to gauge the time span in which the population trajectory and status of the Humpback Chub can be reasonably predicted with consideration of ongoing and future management actions. To better understand this concept, we draw from the opinion of the Solicitor for the Department of the Interior in describing "The Meaning of 'Foreseeable Future' in Section 3(20) of the Endangered Species Act" (U.S. Department of the Interior 2009). "Foreseeable future" is the applicable time frame that is part of the definition of a threatened species from the ESA as *"…any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range." 16 U.S. C. § 1532(20)*.

Foreseeable future describes the extent to which the Service can, in making determinations about the future conservation status of a species, reasonably rely on predictions about the future. Those predictions can be in the form of extrapolation of population or threat trends, analysis of how threats will affect the status of the species, assessment of future events that will have a significant new impact on the species, and the efficacy of ongoing and future management actions. The Service's ability to rely on predictions may significantly vary with the amount and substance of available data and information.

Biologically meaningful time frame for the Humpback Chub is derived from generation time,[12] population trends, and the offsetting effect of management actions on threats. In the upper basin, generation time is derived from the age of female maturity of 5 years and average annual adult mortality of 0.33 (Howard and Caldwell 2017; Francis et al. 2016; Hines et al. 2016); i.e., 5 + (1/0.33) = 5 + 3 = 8 years. In Grand Canyon, longevity is artificially enhanced by cold temperature, and generation time is derived from an average age of maturity of 8 years (Yackulic et al. 2014) and an annual adult mortality of 0.13 (Coggins and Walters 2009); i.e., 8 + (1/0.13) = 8 + 8 = 16 years. This generation time is not applied to

[12] Generation time is defined as the average interval of time between the birth of parents and the birth of their offspring (Campbell et al. 1999).

the species elsewhere in the Colorado River System because the effect of cold dam releases affects only the Grand Canyon population.

Within this SSA, the viability of the species is evaluated a biologically meaningful timeframe of 16 years. A period of 8 years is used as the generation time for the Humpback Chub and as the time period in which changes in population trajectory are apparent (see section 4.5.5). Two generation times, or 16 years, is established as the short-term time frame, or the period of time in which population structure and demographics will enable populations to persist, with the help of ongoing threats management. The Science Advisory Subgroup evaluated the short-term timeframe, presented in Chapters 5 and 6.

To fully evaluate the potential risk to the species across longer timeframes, the U.S. Fish and Wildlife Service developed a means to consider the species condition up to 40 years into the future (Appendix C). This process provided consideration of the future condition of the species over additional generations, evaluated longer term changes in resource condition, and incorporated the uncertainty of a longer-term future.

5.2 Risks and Uncertainties

This species status assessment discusses several risks and uncertainties faced by the Humpback Chub in maintaining redundancy, resiliency, and representation for a biologically meaningful time frame. These risks fundamentally translate into species threats, which are incorporated into the future scenarios in Section 5.3 and may be considered in the species recovery plan. Some of these threats are overt, ongoing, and evident. Others are insidious and more uncertain as to their present and future effect on the species. The following summarizes these risks and uncertainties:

1. **Less Stream Flow—**All six populations of Humpback Chub are at risk from altered stream flow in the future. Significant surface-flow reductions are not expected, but periodic drought or groundwater withdrawals may further reduce flow. Episodes of drought have been seen in the last 6 decades. These episodes have led to higher air and water temperature, increased evaporative losses, and decreased stream flow. Decreased stream flow will reduce habitat, stress food supply, and exacerbate species inter-actions that can lead to increased predation and competition, as well as an increased likelihood of competition and hybridization with Roundtail Chub. The following describes risk management in the basins.
    a. In the upper basin, flow recommendations have been developed and are being applied (see Table 4 above), evaluated, and revised to provide a flow regime beneficial to the native fishes. Revised flow management provides Humpback Chub with more natural and consistent flow conditions, which is a great improvement from past decades, especially the early 2000 drought period.
    b. In the lower basin, flow of the Colorado River through the Grand Canyon is regulated by Glen Canyon Dam that is managed by the Law of the River and

the 2016 LTEMP EIS, which attempts to balance dam management with protection of resources, including the Humpback Chub.

Uncertainties exist as to the ability of stakeholders to provide current flow management actions into the future, thus impacting predictions of future stream flow conditions. A number of potential situations could decrease stakeholder ability to meet flow recommendations, such as increased demand on Colorado Basin Compact water and decreased supply from reduced water availability. Lack of legal protection for flows to benefit native fish decreases the certainty of flow management, although in many locations flow recommendations are codified under legal documents under NEPA or other agreements.

2. **Higher Water Temperature—**Warmer stream temperatures are evident throughout the Colorado River System for the last six decades. While warmer stream temperatures would likely have no impact, or beneficial impact, to Humpback Chub, warming stream temperatures increase the risk of nonnative fish establishing among Humpback Chub populations. The following describes the risk for the basins.
    a. In the upper basin, temperature-degree-days have increased with no apparent effect to Humpback Chub, but possibly better conditions for nonnative fishes. Increased frequency of below-average annual snowpack would increase the frequency of Smallmouth Bass production. Smallmouth Bass production outside of Humpback Chub populations increases the emigration of predatory individuals and increases the risk of establishment within areas occupied by Humpback Chub.
    b. Increased stream temperatures could increase the likelihood of Humpback Chub recolonizing Whirlpool Canyon if releases from Flaming Gorge Dam increase in temperature.
    c. In the lower basin, Humpback Chub have been able to maintain a population in the Colorado River despite cold dam releases by spawning in the seasonally-warmed LCR. Humpback Chub are able to reside in the cold mainstem, where body condition is enhanced, growth is slowed, and longevity is extended. Decreased stream flow is likely to result in lower levels of Lake Powell that will result in warmer downstream releases. Increased water temperature in the Grand Canyon could lead to improved food supply, but could also lead to increased abundance of Brown Trout, Green Sunfish, Smallmouth Bass, Walleye, and other cool and warm-water predators. Warmer water can also lead to an increase in mainstem spawning of Humpback Chub and increased growth of individuals—if food supply is suitable.

Uncertainties exist as to the response of nonnative fish to warmer stream flow conditions. Nonnative fish may not expand their range in response to warmer conditions, but instead be limited by habitat availability. Conversely, warmer stream flow conditions may allow nonnative fish to expand their ranges and increase their occurrence with Humpback Chub, especially Smallmouth Bass in the upper basin and

Green Sunfish and Smallmouth Bass in the lower basin. Independent of nonnative fish concerns, warmer stream temperatures are likely beneficial to Humpback Chub, especially in locations near dams such as Glen Canyon and Flaming Gorge.

3. **Pumping from the Coconino Aquifer—**Considerable groundwater is pumped from the Coconino aquifer that underlies the LCR Basin in north-central Arizona. Pumping from this aquifer could reduce stream volume of:
    a. The Blue Springs complex and reduce flow in the lower 18 km of the LCR that is currently a critical component of Humpback Chub habitat in the Grand Canyon; and
    b. Havasu Springs that discharges into Havasu Creek where Humpback Chub have recently been successfully translocated, with subsequent evidence of reproduction and recruitment.

    Uncertainties exist as to the likelihood and extent of any pumping from the Coconino Aquifer, but based on past data, it is anticipated that groundwater levels will continue to drop, potentially negatively impacting the base flow of the LCR.

4. **Parasites and Diseases—**Parasites and diseases generally do not pose a large risk to the Humpback Chub. The following summarizes this risk to the species by basin.
    a. In the upper basin, parasites and diseases do not appear to pose a significant threat to Humpback Chub.
    b. In the lower basin, the Asian tapeworm is common in the LCR, and is carried by infected fish into the mainstem where warming temperatures could enable this parasite to complete its life history. Fish being translocated to other locales from the LCR are being cleansed of parasites and diseases before the fish are released into the wild.

    Uncertainties exist as to the introduction of a new parasite or disease into Humpback Chub populations, although the likelihood of this introduction is currently believed to be quite low.

5. **Predation and Competition by Nonnative Fish—**Eighteen species of nonnative predators and competitors currently occur with the Humpback Chub. Most notable are Smallmouth Bass, Channel Catfish, Largemouth Bass, Walleye, and Northern Pike (see section 4.1.4). Densities of these nonnative fish in Humpback Chub habitat vary based on ecological conditions, with the most concerning being Smallmouth Bass. Because densities of these nonnative fish are either not meaningful (Walleye and Northern Pike), low (Largemouth Bass), unchanged for almost a century (Channel Catfish), or cyclical (Smallmouth Bass), we hypothesize that the arduous canyon habitats are effectively reducing colonization of these fish. Although actions to control nonnative fish basin-wide are removing large number of fish and suppressing

densities, the long-term efficacy of these efforts remains uncertain. The following are specific areas where this risk poses a threat to the species.

a. Smallmouth Bass, Northern Pike, and Channel Catfish are predaceous introduced fishes which have established reproducing populations in certain locations in the upper Colorado River System. Walleye and Largemouth Bass are predaceous introduced fishes that exist in the river primarily from emigrating from reservoirs (or ponds).
b. Channel Catfish reside and recruit in Humpback Chub population areas; Smallmouth Bass occur in a subset of Humpback Chub population areas but rarely recruit there; Largemouth Bass can occur and do not recruit in Humpback Chub population areas; Northern Pike and Walleye are rare or absent from Humpback Chub population areas.
c. Smallmouth bass are common in Desolation Canyon and have apparently expanded their range downstream throughout the canyon over the last decade, are present in low densities in the Dinosaur National Monument and Black Rocks populations, and are rare in other Humpback Chub populations.
d. Smallmouth Bass density and size structure in canyon habitats are influenced by upstream production rather than local production.
e. Rainbow Trout and Brown Trout reside in the Colorado River in Grand Canyon, and Green Sunfish, Smallmouth Bass, and Walleye potentially could expand there.
f. Channel Catfish, Green Sunfish, and Common Carp reside in the LCR.

Two primary uncertainties surround the relationship between Humpback Chub and nonnative fish. First, the effectiveness of management actions to control nonnative fish in the upper basin is unknown. Although actions are guided by robust scientific evaluation, are funded and implemented at near-maximum capacity, and are accomplished at an immense geographic scale, we cannot claim that the actions are assured to reduce the threat of nonnative fish. Current management techniques may simply be inadequate. Second, the canyons inhabited by Humpback chub may not be as resistant to colonization of Smallmouth Bass as we believe them to be. Currently, our best scientific judgment indicates that both management actions are appropriate and Humpback Chub habitats are resistant to colonization. However, we cannot ignore the uncertainty of these beliefs.

6. **Water Quality and Contaminants—**A number of contaminants enter the Colorado River on a regular basis from municipal, agricultural, and industrial sources, but the susceptibility of the Humpback Chub to these contaminants is undetermined. The following are specific areas where this risk poses a threat to the species.

a. Agricultural pesticides, pharmaceutical drugs such as immune suppressants and hormones, various industrial chemicals, heavy metals, and petroleum products accumulated from throughout the basin.
b. Selenium from Mancos shale in the upper basin.
c. Mercury from local emissions, such as coal-fired power plants, and from air-borne fallout.

The impact of municipal, agricultural, and industrial contaminants in populations of Humpback Chub is highly uncertain. At this time we have no data to indicate that these contaminants are a large impact to the species, but new information could change that hypothesis.

7. **Catastrophic Events—**Catastrophic events are natural or human-related phenomena that can kill or displace fish, or impose severe stress on a population, all of which can lead to short-term or long-term population decline. The following are potential and actual catastrophic events that may kill or displace Humpback Chub.

    a. Large ash-laden floods following wild fires and heavy rainstorms. These have occurred in Westwater Canyon and Desolation/Gray canyons of the upper basin, and in Shinumo Creek in the Grand Canyon.
    b. Petroleum pipeline ruptures. An oil spill occurred in the Yampa River from a petroleum product pipeline ruptured that released an unknown volume of material into the river with unknown effect to the native fish populations.
    c. Petroleum well rupture. A petroleum well ruptured near the Green River that released material into the Desolation/Gray canyons area with unknown effect.
    d. Riverside railways that carry various toxic materials run parallel to the Colorado River at Black Rocks and Westwater Canyon.
    e. Petroleum product pipelines that cross rivers or are within the 100-year floodplain.
    f. Spills from overland trucking, such as from the U.S. Highway 89 Bridge at Cameron, AZ on the LCR.

    It is uncertain how likely a catastrophic event is to occur and the impact of a spill on humpback chub would depend on the substance. At this time, it appears unlikely that a catastrophic event would take place, considering standard safety protocols. Moreover, the existence of multiple populations of Humpback Chub mitigates this impact.

8. **Reduced Genetic Diversity—**The genetic diversity of five of the six populations of Humpback Chub appears to be relatively high and stable (except for DNM). The following cast some uncertainty on the long-term genetic diversity of the species.

a. Glen Canyon Dam has separated the upper basin populations from the lower basin since 1963, with no chance of natural movement or exchange of individuals or genetic material. Although this isolation does not appear to have had a detrimental effect on genetic diversity, some genetic drift would be expected with time, and the genetic status of these populations should continue to be monitored.

b. Small populations are more subject to the loss of genetic diversity, such as seen with the DNM population.

c. Hybridization of Humpback Chub with Roundtail Chub and possibly Bonytail in the upper basin could exacerbate loss of alleles and adaptive traits. This could affect representation of the species, especially in the upper basin, and it may be prudent to investigate strategies for ensuring genetic diversity and viability in both the upper and lower basins.

9. **Population Trajectories—**Humpback Chub population trajectory is important for understanding species viability, but is uncertain for the upper basin populations.

   a. One population in the upper basin, Dinosaur National Monument, is below detection limits and is considered functionally extirpated.

   b. The numbers of adult abundance estimates for two of the five populations of Humpback Chub in the upper basin are too few and varied for a reliable projection of population trajectory.

   c. For populations where numbers of fish are sufficient and estimates are reliable (Black Rocks and Westwater Canyon), the time period of estimates appears to span only a part of the demographic cycle.

   d. CPUE indices that span a longer time period and that precede abundance estimates remain relatively consistent, but current estimates are insufficient to confirm this pattern.

   e. For the other upper basin populations, abundance estimates are too varied (Desolation/Gray canyons), numbers of fish are low (Cataract Canyon), or fish are nearly absent (DNM), and little can be said of the trajectory of these populations.

   f. Age-specific vital rates (e.g., survival, recruitment, growth) are not available to conduct a population viability analysis (PVA) for upper basin populations.

   g. For the Grand Canyon population, however, adult abundance estimates appear to show a complete demographic cycle, and vital rates are sufficient to understand that the population is on a stable trajectory.

Evaluating the population trajectories of Humpback Chub includes many sources of uncertainty, including sampling bias. For a long-lived species such as Humpback

Chub, evaluating population changes as either meaningful indices of change or as natural variability often requires long, robust datasets. This data exists in the Grand Canyon, but data in the upper basin is more infrequent and includes fewer captures. Recently, upper basin populations have apparently seen a measurable decline from the early 2000s, and potentially those declines have recently been arrested. However, without prolonged monitoring we cannot conclude with certainty if these populations are responding to management or experiencing natural variation in population dynamics.

10. **Efficacy and Intensity of Management Actions**—Conservation of the Humpback Chub is being coordinated by three principal programs that consist of stakeholders from federal, state, private, and tribal interests (see section 4.4). These programs are largely federally funded and renewed on a periodic basis. The programs implement and maintain actions vital for offsetting species threats and contributing to species recovery. Support and funding for these programs can be uncertain, depending on species status and trajectories, environmental conditions, and the current administrative and political atmosphere.

    The following is an overview of these programs.

    a. The Upper Colorado River Endangered Fish Recovery Program has been in place since 1988 and coordinates recovery for the Colorado Pikeminnow, Humpback Chub, Razorback Sucker, and Bonytail in the upper basin. The Program is currently funded through September 30, 2019 (with anticipation that funding will be extended through 2023).
    b. The Glen Canyon Dam Adaptive Management Program was established in 1997 with the Grand Canyon Protection Act, and is a Federal Advisory Committee with biennial funding renewal.
    c. The Lower Colorado River Multi-Species Conservation Program was implemented in 2005 and is funded annually.

    Two primary uncertainties surround the current management actions considered previously in this document: continued implementation of the actions; and effectiveness of the actions. Commitment to future funding and implementation of stakeholder management for the benefit of Humpback Chub is strong among the various partnerships. However, some of these Programs are not funded over the entire biologically meaningful timeframe analyzed here. Encouragingly, some specific management actions would remain in place, even without these programs, such as flow management analyzed under NEPA. However, other actions, most notably nonnative fish removal would not necessarily be continued without the programs. Even if programs continue in their current form and funding level, effectiveness of some management actions is uncertain. As previously discussed, both stream flow management and nonnative fish management may not have the desired effect on

Humpback Chub if water is unavailable or if nonnative fish management is ineffective.

11. **Reduced Water Availability**—Future manifestations of reduced water availability remain one of the biggest uncertainties for the hydrology of the Colorado River System. Shifts in hydrology and temperature in the last few decades may be a new long-term condition or may be within the range of system variability. These shifts have resulted in warmer water temperature, increased evaporation, reduced stream flow, and a shift from winter snow storage to spring snow/rain mix. All projections indicate that this pattern is likely to continue. The biggest future effect on the Humpback Chub will be an increased frequency of drought episodes, characterized as multiple consecutive years of low spring flow. This condition appears to reduce reproduction and recruitment in populations, and allows expansion of nonnative fish and Roundtail Chub into upper basin populations. Reduced annual river volume will also lower the elevation of Lake Powell and increase dam release temperature in the Grand Canyon, with a consequent potential increase in nonnative fish, such as brown trout (Al-Chokhachy et al. 2016).

5.3 Future Condition of Populations

The future condition of the Humpback Chub over the biologically meaningful timeframe of 16 years is expected to be driven largely by streamflow, stream temperature, and population dynamics of nonnative fish, although other resource conditions are important. Management actions for specific resource conditions further influence the future condition of the species. The UCRRP, GCDAMP, and LCR MSCP have implemented a suite of actions that improve resource conditions, especially stream flow, stream temperature, and impacts from nonnative fish; these actions ameliorate human effects as well as effects of reduced water availability and help to conserve the suite of native species that inhabit this region of the Colorado River.

Flow and temperature of the Colorado River System have been influenced for the last century by human activities that have regulated hydrology basin-wide and altered river temperature in short reaches below impoundments. This reduced flow and altered temperature have been exacerbated in the last 5-6 decades by periods of drought. These periods are marked by reduced stream flow, increased air temperature, and enhanced evaporation that are likely to continue and result in a number of ecological consequences, including, but not limited to reduced habitat availability, increased abundance and expansion of nonnative predaceous and competitive fish species, altered food supplies, and shifts in reproductive timing. Flow and temperature recommendations have been developed for the major rivers of the upper basin (Table 4), and even more importantly these recommendations have been applied. In the Grand Canyon, Glen Canyon Dam releases are coordinated through operating criteria in the LTEMP EIS (U.S. Department of the Interior 2016) and in the Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations of Lake Powell and

Lake Mead EIS (U.S. Department of the Interior 2007). A temperature control device, installed on Flaming Gorge Dam in 1978, has warmed downstream releases for the Green River and allowed for upstream expansion of native fishes into Lodore Canyon (Bestgen et al. 2006). This warming could provide more suitable conditions for reestablishment of the Humpback Chub population in Whirlpool Canyon. In the lower basin, the Bureau of Reclamation has implemented feasibility studies for warming releases from Glen Canyon Dam. Warmer releases from the dam starting in 2004 have provided insight to possible beneficial effects of warming on native fishes in Grand Canyon, but warming could also benefit the nonnative fishes.

The UCRRP and its partners currently remove problematic nonnative fish species from nine river reaches of the upper basin on the Yampa, Green, Colorado, White, Duchesne, and Gunnison rivers (Tables 8 and 9). The species targeted for removal include: Smallmouth Bass, Northern Pike, Channel Catfish, Largemouth Bass, and Walleye, although other nonnative species are also removed as encountered. Removal efforts are adjusted annually to account for species ranges, densities, and environmental conditions. A Nonnative Fish Control Environmental Assessment was implemented in the Grand Canyon in 2012 to help conserve native fish, particularly the Humpback Chub, by taking necessary actions to reduce numbers of nonnative fish, especially Rainbow Trout and Brown Trout in the Colorado River downstream of Glen Canyon Dam (U.S. Department of the Interior 2011). Efforts to mechanically remove nonnative fish were effective, but these target species recovered quickly after removal was suspended (Coggins 2008). The 2016 LTEMP EIS (U.S. Department of the Interior 2016) and the 2013 Comprehensive Fisheries Management Plan (National Park Service 2013) help to define future actions for controlling nonnative fish in the Grand Canyon. Although mechanical nonnative fish control strategies are in place in Grand Canyon, it is uncertain if mechanical removal in the mainstem Colorado River would be effective during large Rainbow Trout recruitment years, and/or if Brown Trout increase in abundance in Glen Canyon and other areas and expand into the LCR inflow area.

As described in section 5.2, there are important uncertainties to consider about the future of resource needs for Humpback Chub and how management actions will impact those conditions. To assess possible future condition, the U.S. Fish and Wildlife Service selected three possible future scenarios of ecological conditions. The scenarios included varying implementation and effectiveness of active and adaptive management. The Science Advisory Team then evaluated the changes in ecological condition and resultant changes in resource conditions. Based on this evaluation, principal among the resource conditions impacting Humpback Chub are stream flow and temperature, and nonnative fish populations. It is important to note that all future scenarios assume that the risk from nonnatives will increase and availability of water will be lower (see Appendix B).

- Scenario 1 [Environmental Stressors Increase and New or Discretionary Extralegal Actions are Eliminated]—includes an elimination of some active and adaptive actions, and a reduction in voluntary management actions for the species, such that many stakeholder actions are no longer in place to mitigate future conditions including decreased water availability, future water development, or nonnative fish. Conservation actions codified under binding agreements (NEPA, Section 7) would continue. For example, instream flows are not legally protected any more than they are today (e.g. RODs, PBOs remain in effect), some voluntary flow management actions diminish, and nonnative fish management is not continued in the Upper Basin. In the Lower Basin, water management, nonnative fish control, and other actions would remain consistent with the current level of effort prescribed by various RODs and ESA section 7 consultations, but no new or adaptive actions would take place. Although a greater proportion of actions in the Lower Basin are legally required, in this scenario it is expected that management actions are not adaptive or effective and are unable to respond to impacts from various stressors causing population declines of Humpback Chub in both basins.

- Scenario 2 [Legally Mandated Management Actions and Additional Adaptive Management Actions Occur, but are Ineffective]—in addition to minimum actions required under Scenario 1, additional proactive and adaptive stakeholder agencies' management practices occur into the future for the species, but these actions are ineffective to mitigate impacts of drought, future water development, nonnative fishes, or other threats. For example, water operations cannot provide adequate flows or temperatures in humpback chub habitats because drought or other factors have decreased water supply, or nonnative fish colonize Humpback Chub habitat in high densities despite stakeholder action. In this scenario, it is expected that management actions respond to the impacts from various stressors but are not effective to prevent Humpback Chub declines.

- Scenario 3 [Legally Mandated Management Actions and Adaptive Management Actions Occur, and Are Effective]—in addition to minimum actions required under Scenario 1, additional proactive and adaptive stakeholder agencies' management practices occur into the future for the species, and these actions are sufficient to mitigate impacts of drought, future water development, nonnative fishes, or other threats. For example, water operations have the flexibility to provide adequate flows and temperatures to and nonnative fish do not colonize or are effectively managed in Humpback Chub habitat. In this scenario, it is expected that management actions respond to the impacts from various stressors causing population declines, and are adequate to stabilize and increase Humpback Chub populations.

For each of the potential future scenarios, the overall effect expected to occur within each population is described below and then summarized in Tables 16, 17 and 18 for Scenarios 1, 2, and 3 respectfully.

5.3.1 Scenario 1: Environmental Stressors Increase and New or Discretionary Extralegal Actions are Eliminated

Black Rocks—The Black Rocks population represents a dense (~400 chub per mile) grouping of Humpback Chub, occupying a small reach of the upper basin where the Colorado River has carved a channel through an upthrust of Precambrian schist and gneiss. This formation is hard and resistant to short-term erosion and is likely to persist for many years with or without active management, although some encroachment from nonnative tamarisk may occur.

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 (upstream of the confluence with the Gunnison River) could diminish. The deep canyon habitats would concentrate water, limiting direct effects, but possibly reduce movement outside the population. River temperature is expected to warm, but the effect on fish 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.

Predation/competition from nonnative fish would be the greatest future threat for this population, which would be exacerbated by warming river temperatures, especially for Smallmouth Bass. Reduced management of nonnative fish both above and below the canyon habitats would increase pressure from nonnative fish in the canyons themselves. Reduced flow may encourage establishment of a nonnative predator, which would severely stress the population and reduce recruitment in the population. The risk for increase and expansion of nonnative fish is greatest in consecutive years of low flow which would occur more often without management.

Westwater Canyon—The Westwater Canyon population is the second largest population in the upper basin and represents a dense (~400 chub per mile) grouping of Humpback Chub. This population is found in a deep canyon with confined walls, where the river has carved through Precambrian schist and gneiss. The canyon is a popular whitewater rafting area that is managed, and will continue to be protected, by the Bureau of Land Management, although some encroachment from nonnative tamarisk may occur.

Reduced stream flow and increased temperature have similar effect as in Black Rocks, and the food supply appears suitable and stable into the future. Reclamation's ROD at the Aspinall Unit and other long-term flow commitments protect against extreme low flows. Voluntary flow management in the upper Colorado River (upstream of the confluence with the Gunnison River) could diminish. Reduced stream flows caused by reduced snowpack would not be actively managed and would result in low water conditions, especially in late summer. The deep canyon habitats would concentrate water, limiting the negative effects of flow. Movement between populations other than Black Rocks may be limited by reductions in flow.

As in Black Rocks, predation/competition from nonnative fish could be the greatest future threat to this population, which would be exacerbated by increasing temperatures. Reduced management of nonnative fish both above and below the canyon habitats would increase pressure from nonnative fish in the canyons themselves. Reduced flow may encourage establishment of a nonnative predator, which would severely stress the populations. The risk for increase and expansion of nonnative fish is greatest in consecutive years of low flow which would occur more often without management.

Desolation/Gray Canyons—The Desolation/Gray canyons population is the largest population in the upper basin. Humpback chub, in moderate densities, occupy the largest reach of the Green River through two canyons confined by high talus slopes and characterized by deep pools, large eddies, and rapids. The canyon is a popular whitewater rafting area that is managed, and will continue to be protected, by the Bureau of Land Management and the Ute Tribe, although some encroachment from nonnative tamarisk may occur.

Reduced stream flow would increase without active management because flows are heavily impacted by upstream reservoir operations. Operation of Flaming Gorge would continue under the 2006 ROD, which would prevent catastrophic low flows. Increases in water demand or decreases in water supply could limit the operation Flaming Gorge to primarily drier hydrologic conditions, which would improve conditions for Smallmouth Bass in nearby habitats.

The risk from predation/competition by nonnative fish would increase substantially, because Smallmouth Bass have already recently increased in range within Desolation/Gray canyons. Smallmouth Bass would likely establish resident populations, severely limiting recruitment in the Humpback Chub population. Without management, this trend would likely continue and threaten the persistence of the population.

Cataract Canyon—The Cataract Canyon population is the smallest extant population of Humpback Chub. The canyon habitat, administered by the National Park Service, is likely protected from future modifications. In fact, increased drought may continue to decrease the water level in Lake Powell, exposing more habitat for colonization.

Located below the confluence of the Colorado and Green rivers, Cataract Canyon water supply is the most consistent of all Humpback Chub populations. Flow management does impact flows in the canyon, but not to the degree of others in the Upper Basin. Individual basin snowpack variability is dampened by its downstream location; therefore removal of management would have a relatively small impact on this population. Also the severe hydrological conditions of Cataract Canyon may limit abundance of all fish species, provide an ample supply of food, and dampen the effect of drought. Little management of nonnative fish currently exists in this population because nonnatives (primarily Walleye) appear to only migrate through Cataract Canyons.

The primary risk in this population is its small size, which is more vulnerable to stochastic extinction events. Without management, dramatic reductions in population size could go unnoticed and unaddressed.

Dinosaur National Monument.—The population of DNM which previously inhabited Yampa and Whirlpool Canyons, is currently below detection limits and is considered functionally extirpated. Without active management, such as a translocation or introduction effort, this population will remain extirpated. Some species needs may remain in acceptable conditions despite the absence of Humpback Chub. Canyon habitat will continue to be protected by the National Park Service, including management against nonnative tamarisk.

Occurrence of reduced stream flows would increase in Yampa Canyon without active management because flows are heavily impacted by upstream water use. Extreme low flow conditions would likely exist, as they did in the early 2000s prior to water management. Any fish that did recolonize the area of Yampa Canyon could be extirpated under these low flows. Stream flow would decrease in Whirlpool Canyon without active management, but extreme low flows would be prevented by Flaming Gorge Dam operations. Operation of Flaming Gorge would continue under the 2006 ROD (U.S. Department of the Interior 2006), which would prevent catastrophic low flows. Increases in water demand or decreases in water supply could limit the Flaming Gorge operation to primarily drier hydrology conditions.

Predation/competition from nonnative fish could be the greatest future threat to this population. Reduced management of nonnative fish both above and below the canyon habitats would increase pressure from nonnative fish in the canyons themselves. Reduced flow would increase nearby production and may encourage establishment of a nonnative predator, which would severely stress the populations. In previous low flow years, smallmouth bass have increased to ~10% of the fish community; this percentage could be higher under scenario 1. The risk for increase and expansion of nonnative fish is greatest in consecutive years of low flow which would occur more often without management.

The combination of these threats makes reestablishment of a functional population highly unlikely.

Grand Canyon—The Grand Canyon population is the largest population of Humpback Chub. The physical habitat is largely intact, and available sediment will continue to be managed by flow agreements already in place. The future flow regime is described in the 2016 LTEMP EIS (U.S. Department of the Interior 2016), in which GCD releases are designed to benefit canyon resources. Future river temperature is somewhat uncertain. If drought continues and Lake Powell continues to drop in elevation, warm dam releases will continue during the fall, with consequent potential effects including increased abundance and distribution of nonnative fish. The food base is in poor condition and would be expected to worsen without active management.

Predation/competition by Rainbow Trout and Brown Trout is likely to continue, and without management, could begin to dramatically impact the population. Alternatively, warming conditions could promote the establishment of a new nonnative predator. Smallmouth Bass, Walleye, or other nonnatives may expand in numbers and distribution and lead to more predation on young Humpback Chub. Catastrophic events may continue to affect tributaries, if conditions such as wild fires are followed by heavy rainstorms and ash-laden floods or debris flows. Impediment to movement between the upper and lower basins will persist with the presence of Glen Canyon Dam, and it may be necessary at some future time to mix fish across basins.

Perhaps the least recognized future threat to the Grand Canyon population is continued pumping of water from the Coconino aquifer, which is the source of water for base flow of the LCR and Havasu Creek. Effects of groundwater pumping are largely unknown.

Populations are likely to continue to reproduce and recruit, but numbers may be reduced. The current population size protects from a variety of potential threats.

Table 16. A summary of the future condition of species needs under Scenario 1 for the six populations of the Humpback Chub. Color codes: dark green = resource condition is good, light green = fair; yellow = neutral; orange = poor; red = bad.

Resource Category	Black Rocks	Westwater Canyon	Desolation/Gray canyons	Cataract Canyon	Dinosaur National Monument	Grand Canyon
1. Diverse rocky canyon river habitat	**Good** • Physical habitat of optimal condition. • Intact, protected and likely to persist. • Some encroachment by nonnative tamarisk but immeasurable effect to habitat.	**Good** • Physical habitat of optimal condition. • Intact, protected and likely to persist. • Some encroachment by nonnative tamarisk but immeasurable effect to habitat.	**Fair** • Physical habitat intact but consists of mostly talus reaches . • Protected and likely to persist. • Some encroachment by nonnative tamarisk but immeasurable effect to habitat.	**Fair** • Physical habitat intact but consists of mostly talus reaches. • Protected and likely to persist. • Some encroachment by nonnative tamarisk but immeasurable effect to habitat.	**Fair** • Physical habitat intact but consists of mostly talus reaches . • Protected and likely to persist. • Some encroachment by nonnative vegetation armors cobble bars and limits spawning	**Good** • Physical habitat of optimal condition. • Largely intact, available sediment managed by flow.
2a. Suitable flow	**Poor** • Water availability and lack of adaptive management could dramatically reduce flows suitable for Humpback Chub. • Reclamation's ROD at the Aspinall Unit and other long term flow commitments protect against catastrophic low flows.	**Poor** • Water availability and lack of adaptive management could dramatically reduce flows suitable for Humpback Chub. • Reclamation's ROD at the Aspinall Unit and other long term flow commitments protect against catastrophic low flows.	**Poor** • Water availability and lack of adaptive management could dramatically reduce flows suitable for Humpback Chub. • Flaming Gorge operation under 2006 ROD would prevent catastrophic low flows.	**Neutral** • Water availability and lack of adaptive management could dramatically reduce flows suitable for Humpback Chub. • Extreme downstream location mitigates variability of water supply for smaller basins.	**Bad** • Water availability and lack of adaptive management could dramatically reduce flows suitable for Humpback Chub. • Drought conditions could create catastrophic low flows in Yampa Canyon. • Flaming Gorge operation under 2006 ROD would prevent catastrophic low flow in Whirlpool Canyon.	**Neutral** • LTEMP EIS and GCD[a] releases would continue. • Drought could reduce levels in Lake Powell which may restrict flow options under the LTEMP EIS. • Interstate and international agreements require certain flows be delivered downstream.
2b. Suitable temperature	**Neutral** • Temperature is expected to warm, but direct effects on Humpback Chub are not expected.	**Neutral** • Temperature is expected to warm, but direct effects on Humpback Chub are not expected.	**Neutral** • Temperature is expected to warm, but direct effects on Humpback Chub are not expected.	**Neutral** • Temperature is expected to warm, but direct effects on Humpback Chub are not expected.	**Neutral** • Temperature is expected to warm, but direct effects on Humpback Chub are not expected.	**Fair** • Drought-induced low level of Lake Powell likely to result in warmer water releases. • Cold releases from GCD possible but less likely. • Temperature Control Device on GCD will not occur.
3. Adequate and reliable food supply	**Fair** • Food supply is expected to persist, though may be altered by increasing temperatures and decreasing flows.	**Fair** • Food supply is expected to persist, though may be altered by increasing temperatures and decreasing flows.	**Fair** • Food supply is expected to persist, though may be altered by increasing temperatures and decreasing flows.	**Fair** • Food supply is expected to persist, though may be altered by increasing temperatures and decreasing flows.	**Fair** • Food supply is expected to persist, though may be altered by increasing temperatures and decreasing flows.	**Bad** • Food supply is likely to diminish from its current condition, with only substandard items remaining.
4. Habitat with few nonnative predators and competitors	**Bad** • Established nonnative fish populations above and below canyon would expand into Humpback Chub areas and management would not respond. • Invasion of a new predatory species could cause serious predation/ competition effects.	**Poor** • Established nonnative fish populations above and below canyon would expand into Humpback Chub areas and management would not respond. • Invasion of a new predatory species could cause serious predation/ competition effects.	**Bad** • Established nonnative fish populations above and below canyon would expand into Humpback Chub areas and management would not respond. • Invasion of a new predatory species could cause serious predation/ competition effects.	**Neutral** • Invasion of a new nonnative species could cause serious effects from predation/ competition. • Location, habitat conditions and continued attempts at management likely to prevent severe impacts in this population.	**Bad** • Established nonnative fish populations above and below canyon would expand into Humpback Chub areas and management would not respond. • Invasion of a new predatory species could cause serious predation/ competition effects.	**Poor** • Invasion of an unmanageable species could cause serious effects from predation/ competition. • Nonnatives outside LCR aggregation unlikely to be managed.

Resource Category	Black Rocks	Westwater Canyon	Desolation/Gray canyons	Cataract Canyon	Dinosaur National Monument	Grand Canyon
Habitat with few nonnative predators and competitors (continued)	• Increased temperature would benefit Smallmouth Bass production nearby.	• Increased temperature would benefit Smallmouth Bass production nearby.	• Increased temperature would benefit Smallmouth Bass production nearby.		• Increased temperature would benefit Smallmouth Bass production nearby.	• Redundant populations separated by barriers may prevent severe impacts. • Increased invasion possible as temperatures increase. • No new tools available to manage nonnatives.
5. Suitable water quality	**Poor—Uncertain** • Effects of persistent contaminants on Humpback Chub not well understood. • Without active management, spills may go unnoticed or remain uncontained.	**Poor—Uncertain** • Effects of persistent contaminants on Humpback Chub not well understood. • Without active management, spills may go unnoticed or remain uncontained.	**Poor—Uncertain** • Effects of persistent contaminants on Humpback Chub not well understood. • Without active management, spills may go unnoticed or remain uncontained.	**Poor—Uncertain** • Effects of persistent contaminants on Humpback Chub not well understood. • Without active management, spills may go unnoticed or remain uncontained.	**Poor—Uncertain** • Effects of persistent contaminants on Humpback Chub not well understood. • Without active management, spills may go unnoticed or remain uncontained.	**Poor—Uncertain** • Effects of persistent contaminants on fish not well understood. • Without active management, spills may go unnoticed or remain uncontained. • Threat of spill at Cameron Bridge on LCR has been reduced.
6. Unimpeded range and connectivity	**Fair** • Without managed flows, movement between populations may be impeded. • Populations exist within close proximity, some movement likely to continue.	**Fair** • Without managed flows, movement between populations may be impeded. • Populations exist within close proximity, some movement likely to continue.	**Neutral** • Without managed flows, movement between populations may be impeded.	**Neutral** • Population not in close proximity to others.	**Poor** • Without managed flows, movement between populations may be impeded. • Population not in close proximity to others.	**Fair** • Movement maintained between mainstem & LCR. • Tributary barriers to fish passage are not expected to be modified for passage. • Impediment to movement between upper and lower basins will continue.
7. Persistent population	**Bad** • Poor flow and nonnative fish conditions are expected to severely limit recruitment. • Management unable to arrest declines resulting in elimination of at least one currently persisting population in the upper basin.	**Bad** • Poor flow and nonnative fish conditions are expected to severely limit recruitment. • Management unable to arrest declines resulting in elimination of at least one currently persisting population in the upper basin.	**Bad** • Poor flow and nonnative fish conditions are expected to severely limit recruitment. • Management unable to arrest declines resulting in elimination of at least one currently persisting population in the upper basin.	**Bad** • Small population size is more vulnerable to stochastic population collapse. • Management unable to arrest declines potentially eliminating population.	**Bad** • Effects from less than optimal flow conditions and nonnative fish are expected to prevent the reestablishment of this population.	**Fair** • Core LCR population expected to continue to reproduce and recruit annually.
8. High genetic diversity	**Bad** • Effects from less than optimal flow conditions and nonnative fish are expected to stress populations and reduce the number of individuals, threatening genetic diversity.	**Bad** • Effects from less than optimal flow conditions and nonnative fish are expected to stress populations and reduce the number of individuals, threatening genetic diversity.	**Bad** • Effects from less than optimal flow conditions and nonnative fish are expected to stress populations and reduce the number of individuals, threatening genetic diversity.	**Bad** • Effects from less than optimal flow conditions and nonnative fish are expected to stress populations and reduce the number of individuals, threatening genetic diversity.	**Bad** • Effects from less than optimal flow conditions and nonnative fish are expected to stress populations and reduce the number of individuals, threatening genetic diversity.	**Neutral** • Populations are likely to suffer reductions with presence of unmanaged nonnative species, yet are likely to persist with genetically diverse individuals.

[a] GCD = Glen Canyon Dam

5.3.2 -Scenario 2: Legally Mandated Management Actions and Additional Adaptive Management Actions Occur, but are Ineffective

Black Rocks— Stakeholder commitment to management of this population will provide more flexibility and active response to poor resource conditions, such as streamflow and presence of nonnative fish. However, even with active flow management and nonnative fish removal, it is uncertain if water operations will have the flexibility to provide adequate flows in all years or if nonnative fish management will prevent colonization of Smallmouth Bass.

Reduced stream flows caused by reduced snowpack would be actively ameliorated through management and would result in less frequent low water conditions compared to scenario 1, but low flow years are expected to still occur. Reclamation's ROD at the Aspinall Unit (U.S. Department of the Interior 2012) and other long-term flow commitments protect against extreme low flows, but frequent years of low flow will still negatively impact the population. Substantial decrease in water availability, either from chronically reduced snowpack or increased water demand, could outstrip Reclamation's capacity to provide appropriate flow conditions.

Frequent low flow conditions and increased water temperature would benefit Smallmouth Bass production nearby. Continued management of nonnative fish both above and below the canyon habitats would reduce populations but would be unable to prevent establishment (or periods of establishment) of a nonnative predator, which would severely stress the population and slow recruitment. The risk for increase and expansion of nonnative fish is greatest in consecutive years of low flow which would occur even during flow management. Nonnative fish would likely colonize at lower densities than nearby reaches, but would impact a consistent, long-term impact on the population. The population is moderate in size and is expected to continue to reproduce and recruit annually, albeit likely in a declining state. Genetic diversity is expected to endure, and the population is likely to persist but decline under sub-standard resource conditions. Individual movement between Black Rocks and Westwater populations may assist in population stabilization.

Westwater Canyon— Resource conditions under scenario 2 are expected to be the same as in the Black Rocks population immediately upstream. The primary difference is the increased stream miles occupied by Humpback Chub in Westwater Canyon will likely improve population resilience and slow declines. Also, Westwater Canyon is further downstream from Smallmouth Bass production areas which may decrease the likelihood of colonization or density of establishment of this species.

Desolation/Gray Canyons— Stakeholder commitment to management of this population will provide more flexibility and active response to poor resource conditions, such as streamflow and increased densities of nonnative fish. However, even with active flow management there is uncertainty if Flaming Gorge operations will have the long-term water supply to provide adequate flows in all years. Similarly, it is uncertainty if nonnative fish management will prevent long-term establishment of Smallmouth Bass that are currently expanding their range within the canyon.

Improved flow management over the last decade, combined with future protection of flows in the Green River, should assist in providing suitable conditions for a viable Humpback Chub population. Specifically, the Bureau of Reclamation re-operated Flaming Gorge dam in 2006 to implement flow and temperature recommendations for the endangered fish in the Green River (Muth et al. 2000). However, under certain chronically low snowpack conditions, Flaming Gorge operations may need to operate in the drier hydrologies more frequently than are needed for Humpback Chub resource conditions. Peak and base flow operations intended to provide beneficial conditions for Humpback Chub in Desolation / Gray Canyons may not provide the variability needed over the long-term.

Increased frequency of drier hydrology operations is problematic in this population because Smallmouth Bass increase in density in upstream reaches during those years and then emigrate downstream in Desolation Canyon. Furthermore, Smallmouth Bass recently increased in range within Desolation/Gray canyons, and may establish a resident population if flow conditions allow. While densities of Smallmouth Bass have declined in response to flows not conducive to their production, Flaming Gorge operations may not be able to provide these flows consistently enough. Future nonnative fish removal and management will need to monitor the condition in this habitat and ensure that appropriate actions are taken. Unfortunately, it is uncertain if these actions are sufficient to prevent establishment of Smallmouth Bass in the Desolation Canyon population. Very little exchange of individuals with other population occurs, and it is unlikely that future demographic effects will extend to or from other populations. It is expected that genetic diversity will endure and that this population will persist but decline under this scenario.

Cataract Canyon— Stakeholder commitment to providing flows across multiple basins will likely provide adequate flows for this downstream location. Flows provided in the Colorado and Green rivers will support this population. Only under the most extreme basin-wide drought scenarios will flows not be adequate. However, more habitat will open as Lake Powell levels drop. It is unlikely that nonnative species from Lake Powell or upstream colonize this area. The severe hydrological conditions of Cataract Canyon—because it is located below the confluence of the Colorado and Green rivers—may limit the abundance of all fish species, provide an ample supply of food, and dampen the effect of drought.

However, the Cataract Canyon population is the smallest extant population of Humpback Chub, putting it at greatest risk from a stochastic disturbance or genetic impacts. Since it was reduced in distribution by the filling of Lake Powell, it has remained small. Nevertheless, this population is expected to continue to remain small and persistent under this scenario.

Dinosaur National Monument— The population of DNM, which previously inhabited Yampa and Whirlpool Canyons, is currently below detection limits and is considered functionally extirpated. Management actions can still provide adequate resource conditions that will support an introduction or translocation attempt. Flow and temperature regimes in the Yampa River are largely unregulated, reducing management control. Conversely, nearby Whirlpool Canyon on the Green River is highly controlled by the presence of Flaming Gorge Dam. Modified operations over the past decade, and a temperature control device on Flaming Gorge Dam provide more natural flows and warmer water for the Green River, and are expected to continue into the future. Similar to Desolation Canyon, under certain chronically low snowpack conditions, Flaming Gorge operations may need to operate in the drier hydrologies more frequently than are needed for Humpback Chub resource conditions and which may allow for increased immigration of Smallmouth Bass.

Flow management in Yampa Canyon is expected to improve conditions compared to previous decades that saw the Humpback Chub become extirpated. In 2007, the Recovery Program secured a permanent source of summer augmentation water (5000 acre-feet with an option to lease an additional 2000 acre-feet) in Elkhead Reservoir in the upper Yampa River drainage. The Recovery Program has used the permanent pool every year since 2007 to improve summer base flow conditions in the lower Yampa River, including Yampa Canyon. However, under extreme low flow conditions, this pool of water would be inadequate to supply the entire base flow condition needed by Humpback Chub.

Smallmouth Bass (primarily juvenile sized fish) can comprise as much as 10% of the Yampa Canyon fish community during and following years of high production upstream. Although the species has not colonized Yampa Canyon in high densities over the long term, as it has in adjacent reaches, chronically poor flow conditions could provide opportunity for long-term establishment. Significant efforts are underway to control spawning congregations of Smallmouth Bass in the Yampa River and to eliminate escapement from upstream reservoirs, but it is uncertain if these actions are sufficient to prevent colonization of Yampa and Whirlpool canyons if dry hydrologies become the norm. We expect under scenario 2, Smallmouth Bass density will likely be no more than 10%, but instances of this density will increase in frequency.

Under this scenario, reestablishment of a resident population remains unlikely.

Grand Canyon— The Grand Canyon population is the largest population of Humpback Chub, and is likely to continue to be self-sustained for 16 years with appropriate and effective threats management. The physical habitat is largely intact, and available sediment will continue to be managed by flow. The future flow regime is described in the 2016 LTEMP EIS (U.S. DEPARTMENT OF THE INTERIOR 2016), in which GCD releases are designed to benefit canyon resources. Future river temperature is somewhat uncertain. If drought continues and Lake Powell continues to drop in elevation, warm dam releases will continue during the months of August–October, with consequent potential effects including increased abundance and distribution of nonnative fish. The future of the food supply is also uncertain, and ongoing research is attempting to determine the causes of low food supply and strategies for enhancing instream production.

Predation/competition by Rainbow Trout and Brown Trout is likely to continue, and research is ongoing to better understand management strategy. Stakeholders are collaborating on actions to control this and other potentially invasive species, such as Green Sunfish. Smallmouth Bass and Walleye may expand in numbers and distribution and lead to more predation on young Humpback Chub, if management actions are unable to avert an increase in these nonnative species. The threat of a spill at the Cameron Bridge seems to be reduced with reconstruction of U.S. Highway 89 and the bridge and interchange in that area. Catastrophic events may continue to affect tributaries, if conditions such as wild fires are followed by heavy rainstorms and ash-laden floods or debris flows. Impediment to movement between the upper and lower basins will persist with the presence of Glen Canyon Dam, and it may be necessary at some future time to mix fish across basins.

Movement of fish within the Colorado River in Grand Canyon is expected to continue unimpeded, and translocations of young fish into tributaries above falls and chutes should continue. The core LCR population is expected to continue to reproduce and recruit annually. Mainstem reproduction and recruitment is also expected with warmer water, and range expansion into western Grand Canyon is expected with exposed historical habitat from the receding levels of Lake Mead. This expansion in western Grand Canyon could lead to a second reproduction center of Humpback Chub in the lower basin. Genetic diversity is expected to persist. Pumping of water from the Coconino aquifer could affect populations in this scenario as well.

Table 17. A summary of the future condition of species needs under Scenario 2 for the six populations of the Humpback Chub. Color codes: dark green = resource condition is good; light green = fair; yellow = neutral; orange = poor; red = bad.

Resource Category	Black Rocks	Westwater Canyon	Desolation/Gray canyons	Cataract Canyon	Dinosaur National Monument	Grand Canyon
1. Diverse rocky canyon river habitat	**Good** • Physical habitat of optimal condition' • Intact, protected and likely to persist. • Some encroachment by nonnative tamarisk but immeasurable effect to habitat.	**Good** • Physical habitat of optimal condition. • Intact, protected and likely to persist. • Some encroachment by nonnative tamarisk but immeasurable effect to habitat.	**Fair** • Physical habitat intact but consists of mostly talus reaches. • Protected and likely to persist. • Some encroachment by nonnative tamarisk but immeasurable effect to habitat.	**Fair** • Physical habitat intact but consists of mostly talus reaches. • Protected and likely to persist. • Some encroachment by nonnative tamarisk but immeasurable effect to habitat.	**Fair** • Physical habitat intact but consists of mostly talus reaches. • Protected and likely to persist. • Some encroachment by nonnative vegetation armors cobble bars and limits spawning.	**Good** • Physical habitat of optimal condition, largely intact, available sediment managed by flow.
2a. Suitable flow	**Neutral** • Extreme weather events, especially long term drought, reduce the ability to manage flows suitable for Humpback Chub. • Aspinall Unit operations under the ROD would not have adaptive flexibility to respond to extreme weather conditions.	**Neutral** • Extreme weather events, especially long term drought, reduce the ability to manage flows suitable for Humpback Chub • Aspinall Unit operations under the ROD would not have adaptive flexibility to respond to extreme weather conditions.	**Neutral** • Extreme weather events, especially long term drought, reduce the ability to manage flows suitable for Humpback Chub. • Flaming Gorge operations under the 2006 ROD would not have adaptive flexibility to respond to extreme weather conditions.	**Fair** • Extreme downstream location likely provides adequate flow from a combination of the basins.	**Poor** • Drought will contribute to flow reduction. • Low flow in Yampa River likely to recur which may be severe enough to overwhelm the surplus water managed by the UCRRP. • Flaming Gorge operations under the 2006 ROD would not have adaptive flexibility to respond to extreme weather conditions.	**Neutral** • Flow is determined by LTEMP EIS and GCD[a] releases designed to benefit canyon resources. • Possibility exists that drought could reduce levels in Lake Powell which may restrict flow options under the LTEMP EIS. • Interstate and international agreements require certain flows be delivered downstream.
2b. Suitable temperature	**Fair** • Temperature is expected to warm, but effect on Humpback Chub not expected to be measureable.	**Fair** • Temperature is expected to warm, but effect on Humpback Chub not expected to be measureable.	**Fair** • Temperature is expected to warm, but effect on Humpback Chub not expected to be measureable.	**Fair** • Temperature is expected to warm, but effect on Humpback Chub not expected to be measureable.	**Fair** • Temperature is expected to warm, but effect on Humpback Chub not expected to be measureable.	**Fair** • Drought induced low level of Lake Powell likely to result in warmer water releases. • Cold releases from GCD possible, but less likely as reservoir refilling or Temperature Control Device not expected in this time frame.
3. Adequate and reliable food supply	**Good** • Food supply is expected to persist.	**Good** • Food supply is expected to persist.	**Good** • Food supply is expected to persist.	**Good** • Food supply is expected to persist.	**Good** • Food supply is expected to persist.	**Neutral** • Food supply may continue to be limited. • Management may not be able to increase food production.
4. Habitat with few nonnative predators and competitors	**Neutral** • Increased temperature would benefit Smallmouth Bass production nearby, increasing emigrating predators.	**Neutral** • Increased temperature would benefit Smallmouth Bass production nearby, increasing emigrating predators.	**Poor** • Invasion of Smallmouth Bass could greatly alter fish community. • Colonization of Smallmouth Bass likely slowed through flow	**Fair** • Invasion of a predatory species unlikely based on downstream location. • Location, habitat conditions and continued attempts at	**Poor** • Invasion of Smallmouth Bass could greatly alter fish community. • Colonization of Smallmouth Bass likely slowed through flow	**Neutral** • Invasion of an unmanageable species could cause serious effects from predation or competition.

Resource Category	Black Rocks	Westwater Canyon	Desolation/Gray canyons	Cataract Canyon	Dinosaur National Monument	Grand Canyon
Habitat with few nonnative predators and competitors (continued)	• Populations likely still somewhat protected by nonnative removal actions and natural flow regimes. • Invasion of a new predatory species could cause serious effects.	• Populations likely still somewhat protected by nonnative removal actions and natural flow regimes. • Invasion of a new predatory species could cause serious effects.	and nonnative fish management actions. • Increased temperature would benefit Smallmouth Bass production nearby.	management likely to prevent impacts in this population.	and nonnative fish management actions. • Increased temperature would benefit Smallmouth Bass production nearby.	• Redundant populations separated by barriers may prevent severe impacts. • Additional tools available to manage nonnatives, but few effective.
5. Suitable water quality	**Neutral—Uncertain** • Effects of persistent contaminants on Humpback Chub not well understood. • Emergency response plans and safety shutoff valves on pipelines will reduce threat.	**Neutral—Uncertain** • Effects of persistent contaminants on Humpback Chub not well understood. • Emergency response plans and safety shutoff valves on pipelines will reduce threat.	**Neutral—Uncertain** • Effects of persistent contaminants on Humpback Chub not well understood. • Emergency response plans and safety shutoff valves on pipelines will reduce threat.	**Neutral—Uncertain** • Effects of persistent contaminants on Humpback Chub not well understood. • Emergency response plans and safety shutoff valves on pipelines will reduce threat.	**Neutral—Uncertain** • Effects of persistent contaminants on Humpback Chub not well understood. • Emergency response plans and safety shutoff valves on pipelines will reduce threat.	**Neutral—Uncertain** • Effects of persistent contaminants on fish not well understood. • Fish kills may continue in tributaries from ash-laden floods and debris flows after wild fires.
6. Unimpeded range and connectivity	**Good** • No impediment for movement to other populations in upper basin. • Fish passage at Price-Stubb, Grand Valley, Government Highline, and Redlands may expand upstream range.	**Good** • No impediment for movement to other populations in upper basin. • Fish passage at Price-Stubb, Grand Valley, Government Highline, and Redlands may expand upstream range.	**Good** • No impediment for movement to other populations in upper basin. • Fish passage at Tusher Wash may expand facilitate movement among populations.	**Good** • No impediment for movement to other populations in upper basin. • Fish passage at Price-Stubb, Grand Valley, Government Highline, Redlands, and Tusher Wash may expand upstream range.	**Poor** • No impediment for movement to other populations in upper basin, but population seems too distant from others to recolonize.	**Fair** • Tributary barriers not expected to be modified for passage. • Translocations of young fish to new locations with mixed success.
7. Persistent population	**Neutral** • Effects from less than optimal flow conditions and nonnative fish are expected to limit recruitment. • Management expected to slow potential population declines. • Population likely to remain with support from Westwater.	**Neutral** • Effects from less than optimal flow conditions and nonnative fish are expected to limit recruitment. • Management expected to slow potential population declines. • Population likely to remain with support from Black Rocks.	**Poor** • Effects from less than optimal flow conditions and nonnative fish are expected limit recruitment.	**Poor** • Effects from less than optimal flow conditions and nonnative fish are expected to stress the population limit recruitment. • Small population size is more vulnerable to stochastic population collapse.	**Bad** • Effects from less than optimal flow conditions and nonnative fish may prevent successful translocation.	**Fair** • Core Little Colorado River population expected to continue to reproduce and recruit annually. • Mainstem reproduction and recruitment expected with warmer dam releases. • Aggregations outside LCR reduced if nonnatives expand and cannot be managed.
8. High genetic diversity	**Neutral** • Uncontrolled nonnative fish expected to stress populations and reduce the number of individuals. • Genetic diversity likely to remain with support from Westwater. • Genetic management actions expected when populations reach critical levels.	**Neutral** • Uncontrolled nonnative fish expected to stress populations and reduce the number of individuals. • Genetic diversity likely to remain with support from Black Rocks. • Genetic management actions expected when populations reach critical levels.	**Neutral** • Uncontrolled nonnative fish expected to stress populations and reduce the number of individuals. • Genetic diversity likely to remain with support from Cataract. • Genetic management actions expected when populations reach critical levels.	**Neutral** • Uncontrolled nonnative fish expected to stress populations and reduce the number of individuals. • Genetic diversity likely to remain with support from Deso/Gray. • Genetic management actions expected when populations reach critical levels.	**Bad** • Unsuccessful translocation does not contribute to genetic integrity of the species.	**Fair** • Populations are likely to persist with genetically diverse individuals. • Some sub-populations protected from nonnative fish invasions by physical structures.

[a] GCD = Glen Canyon Dam

5.3.3 - Scenario 3*:* Legally Mandated Management Actions and Adaptive Management Actions Occur, and Are Effective

Black Rocks—As in the above scenarios, the physical habitat is expected to remain unchanged. Reduced stream flow has affected this population since mainstem dam construction and increased water use, but little additional flow reduction is expected in the future, and is expected to be managed effectively in this scenario. The Bureau of Reclamation and other water managers are managing flows in the upper Colorado and the Gunnison rivers to meet flow recommendations (Osmundson et al. 1995; McAda 2003) for the endangered fish throughout the Upper Colorado subbasin including for Humpback Chub in Black Rocks and Westwater Canyon. River temperature is expected to warm slightly, but the effect on fish is not expected to be measureable. The food supply appears to be good and reliable and is expected to continue to be suitable into the future.

Predation/competition from nonnative fish could be the greatest future threat for this population, and the efficacy of nonnative fish management is vital, especially in years of low flow. The effect of water contaminants is not well understood, but emergency response plans and safety shutoff valves on pipelines will reduce the threat. There is no impediment for movement of individuals to other populations in the upper basin, and recent fish passage at Price-Stubb, Grand Valley, Government Highline, and Redlands may expand upstream range. The population is moderate in size and is expected to continue to reproduce and recruit annually. Despite a large number of Roundtail Chub in Black Rocks, genetic diversity is expected to endure, and the population is likely to persist for 16 years with appropriate and effective threats management.

Westwater Canyon—The Westwater Canyon population is the second largest population in the upper basin. The canyon is a popular whitewater rafting area that is managed, and will continue to be protected, by the Bureau of Land Management. Reduced stream flow and increased temperature have similar effect as in Black Rocks, and the food supply appears suitable and stable into the future. Improved water management will likely improve flow conditions in the future. More appropriate flow conditions in this habitat will therefore support a viable population.

As in Black Rocks, predation/competition from nonnative fish could be the greatest future threat and the efficacy of nonnative fish management is vital. However, despite high densities on nonnative fish in nearby reaches, densities in Westwater Canyon have not fundamentally changed over the past few decades. Consistent nonnative fish monitoring and management will likely help reduce the risk of nonnative fish colonization in this habitat, providing conditions for a viable population. There is no impediment to movement within or from this population, and there is exchange of individuals with the Black Rocks population. The future condition of resources in the Westwater Canyon population is similar to that of the Black Rocks population, and is expected to persist for 16 years with appropriate and effective threats management.

Desolation/Gray Canyons—The Desolation/Gray canyons population is the largest population in the upper basin. It occupies a large reach of the Green River through two canyons confined by high talus slopes and characterized by deep pools, large eddies, and rapids. The canyon is a popular whitewater rafting area that is managed, and will continue to be protected, by the Bureau of Land Management. Reduced stream flow and increased temperature will persist, but no additional effect to the population is expected, except during prolonged episodes of drought.

Improved flow management over the last decade, combined with future protection of flows in the Green River, should assist in providing suitable conditions for a viable Humpback Chub population. Specifically, the Bureau of Reclamation re-operated Flaming Gorge dam in 2006 to implement flow and temperature recommendations for the endangered fish in the Green River (Muth et al. 2000). Those operations promote inter- and intra-annual variability in accordance with a natural flow paradigm and protect flows from reaching extremes in drought years. Those peak and base flow operations are intended to provide beneficial conditions for Humpback Chub in Desolation/Gray canyons as well as for the other endangered species.

Predation/competition by nonnative fish is problematic in this population because Smallmouth Bass recently increased in range within Desolation/Gray canyons, unlike the Black Rocks and Westwater Canyon populations. While densities of Smallmouth Bass have declined in response to flows not conducive to their production, adults have established a more complete range with Desolation/Gray canyons. Future nonnative fish removal and management will need to monitor the condition in this habitat and ensure that appropriate actions are taken. Very little exchange of individuals with other population occurs, and it is unlikely that future demographic effects will extend to or from other populations. It is expected that genetic diversity will endure and that this population will persist for 16 years with appropriate and effective threats management.

Cataract Canyon—The Cataract Canyon population is the smallest extant population of Humpback Chub. Since it was reduced in distribution by the filling of Lake Powell, it has apparently remained small and is expected to persist into the future. The severe hydrological conditions of Cataract Canyon—because it is located below the confluence of the Colorado and Green rivers—may limit the abundance of all fish species, provide an ample supply of food, and dampen the effect of drought. While Walleye and Smallmouth Bass from downstream Lake Powell may migrate through this area, only Channel Catfish are established in the reach. These conditions, however, apparently impose stresses on individual Humpback Chub that limit their body size and reproductive potential. Nevertheless, this population is expected to continue to remain small and persistent for 16 years with appropriate and effective threats management.

Dinosaur National Monument—The population of DNM, which previously inhabited Yampa and Whirlpool Canyons, is currently below detection limits and is considered functionally extirpated. While the flow and temperature regimes in the Yampa River are largely unchanged from historical conditions (with the exception of reduced base flows during the irrigation season), nearby Whirlpool Canyon on the Green River is highly modified by the presence of Flaming Gorge Dam. Modified operations over the past decade, and a temperature control device on Flaming Gorge Dam provides more natural flows and warmer water for the Green River, and are expected to continue into the future. Flow management in Yampa Canyon is expected to be improved as well. In 2007, the Recovery Program secured a permanent source of summer augmentation water (5000 acre-feet with an option to lease an additional 2000 acre-feet) in Elkhead Reservoir in the upper Yampa River drainage. The Recovery Program has used the permanent pool every year since 2007 to improve summer base flow conditions in the lower Yampa River including Yampa Canyon. Flow augmentation could benefit future efforts to repatriate Humpback Chub in DNM.

Smallmouth Bass (primarily juvenile sized fish) can comprise as much as 10% of the Yampa Canyon fish community during and following years of high production upstream. However, the species has not colonized Yampa Canyon in high densities over the long term, like it has in adjacent reaches. Significant efforts are underway to control spawning congregations of Smallmouth Bass in the Yampa River and to eliminate escapement from upstream reservoirs. We expect under scenario 1, Smallmouth Bass density will never exceed 10%, and instances of this density will remain uncommon.

The number of Humpback Chub remaining in this population is probably too low to expect population recovery. Translocations of fish from other populations (as in the Grand Canyon) or stocking of hatchery-reared individuals could reestablish a functional population in this area if coupled by appropriate and effective management of flow (see above) and nonnative fishes.

Grand Canyon—The Grand Canyon population is the largest population of Humpback Chub, and is likely to continue to be self-sustained for 16 years with appropriate and effective threats management. The physical habitat is largely intact, and sediment will continue to be managed by flow. The future flow regime is described in the 2016 LTEMP EIS (U.S. Department of the Interior 2016), in which GCD releases are designed to benefit canyon resources. Future river temperature is somewhat uncertain. If drought continues and Lake Powell continues to drop in elevation, warm dam releases will continue during the months of August–October, with consequent potential effects including increased abundance and distribution of nonnative fish. The future of the food supply is also uncertain, and ongoing research is attempting to determine the causes for low food supply and strategies for enhancing instream production.

Predation/competition by Rainbow Trout and Brown Trout is likely to continue, and research is ongoing to better understand management strategy. An increase in numbers of Brown

Trout in Lees Ferry began in 2013, but stakeholders are collaborating on actions to control this and other potentially invasive species, such as Green Sunfish. Smallmouth Bass and Walleye may expand in numbers and distribution and lead to more predation on young Humpback Chub, if management actions are unable to avert an increase in these nonnative species. The threat of a spill at the Cameron Bridge seems to be reduced with reconstruction of U.S. Highway 89 and the bridge and interchange in that area. Catastrophic events may continue to affect tributaries, if conditions such as wild fires are followed by heavy rainstorms and ash-laden floods or debris flows. Impediment to movement between the upper and lower basins will persist with the presence of Glen Canyon Dam, and it may be necessary at some future time to mix fish across basins.

Movement of fish within the Colorado River in Grand Canyon is expected to continue unimpeded, and translocations of young fish into tributaries above falls and chutes should continue. The core LCR population is expected to continue to reproduce and recruit annually. Mainstem reproduction and recruitment is also expected with warmer dam releases, and range expansion into western Grand Canyon is expected with exposed historical habitat from the receding levels of Lake Mead. The expansion in western Grand Canyon could lead to a second population of Humpback Chub in the lower basin. Genetic diversity is expected to persist. Perhaps the least recognized future threat to the Grand Canyon population is continued pumping of water from the Coconino aquifer, which is the source of water for base flow of the LCR and Havasu Creek. A sudden and substantial decrease in flow in these tributaries—particularly the LCR—could be disastrous to the Humpback Chub population in Grand Canyon.

Table 18. A summary of the future condition of species needs under Scenario 3 for the six populations of the Humpback Chub. Color codes: dark green = resource condition is good; light green = fair; yellow = neutral; orange = poor; red = bad.

Resource Category	Black Rocks	Westwater Canyon	Desolation/Gray canyons	Cataract Canyon	Dinosaur National Monument	Grand Canyon
1. Diverse rocky canyon river habitat	**Good** • Physical habitat of optimal condition. • Intact, protected and likely to persist.	**Good** • Physical habitat of optimal condition. • Intact, protected and likely to persist.	**Fair** • Physical habitat intact but consists of mostly talus reaches. • Protected and likely to persist.	**Fair** • Physical habitat intact but consists of mostly talus reaches. • Protected and likely to persist.	**Fair** • Physical habitat intact but consists of mostly talus reaches. • Protected and likely to persist. • Some encroachment by nonnative vegetation armors cobble bars and limits spawning.	**Good** • Physical habitat largely intact, available sediment managed by flow.
2a. Suitable flow	**Fair** • Little additional flow alteration expected. • Episodes of drought will contribute to flow reduction, but the UCRRP has demonstrated a commitment to spring peak and base flow augmentation throughout the upper basin. • Reclamation's ROD at the Aspinall Unit serves and other long term flow commitments ensure important flow management in the future.	**Fair** • Little additional flow alteration expected. • Episodes of drought will contribute to flow reduction, but the UCRRP has demonstrated a commitment to spring peak and base flow augmentation throughout the upper basin. • Reclamation's ROD at the Aspinall Unit serves and other long term flow commitments ensure important flow management in the future.	**Fair** • Little additional flow alteration expected. • Episodes of drought will contributed to flow reduction but the UCRRP has demonstrated a commitment to spring peak and base flow augmentation throughout the upper basin. • Reclamation's ROD at Flaming Gorge Reservoir and the Elkhead Reservoir supplemental water, and other long-term flow commitments ensure important flow management in the future.	**Fair** • Little additional flow alteration expected. • Episodes of drought will contribute to flow reduction but the UCRRP has demonstrated a commitment to spring peak and base flow augmentation throughout the upper basin. • Reclamation's ROD at the Aspinall Unit and Flaming Gorge Reservoir ensure important flow management in the future.	**Neutral** • Flow regulation of Yampa and Green rivers not expected to change. • Flow reduction in Yampa likely to recur but the UCRRP has secured supplemental water at Elkhead Reservoir to augment summer base flows.	**Neutral** • Flow is determined by LTEMP EIS and GCD[a] releases designed to benefit canyon resources.
2b. Suitable temperature	**Fair** • Temperature is expected to warm, but effect on fish not expected to be measureable.	**Fair** • Temperature is expected to warm, but effect on fish not expected to be measureable.	**Fair** • Temperature is expected to warm, but effect on fish not expected to be measureable.	**Fair** • Temperature is expected to warm, but effect on fish not expected to be measureable.	**Fair** • Temperature is expected to warm, but effect on fish not expected to be measureable.	**Fair** • Drought-induced low level of Lake Powell likely to result in warmer water releases. • Cold releases from GCD possible but less likely as reservoir filling or Temperature Control Device not expected in this timeframe.
3. Adequate and reliable food supply	**Good** • Food supply is expected to persist.	**Good** • Food supply is expected to persist.	**Good** • Food supply is expected to persist.	**Good** • Food supply is expected to persist.	**Good** • Food supply is expected to persist.	**Fair/Enhanced Through Management** • Food supply may continue to be limited; studies are ongoing for better insect production.
4. Habitat with few nonnative predators and competitors	**Fair** • Some predation/competition likely to continue. • Colonization of problematic species is unlikely given past	**Fair** • Some predation/competition likely to continue. • Colonization of problematic species is unlikely given past	**Neutral** • Predation/competition likely to continue. • Monitoring and removal of the expanding Smallmouth Bass	**Fair** • Minor predation/competition likely to continue. • Conditions unlikely to support problematic nonnatives.	**Neutral** • Predation/competition likely to continue.	**Neutral** • Some predation/competition likely to continue but additional effective tools available to control.

Resource Category	Black Rocks	Westwater Canyon	Desolation/Gray canyons	Cataract Canyon	Dinosaur National Monument	Grand Canyon
Habitat with few nonnative predators and competitors (continued)	conditions and future management. • Efficacy of nonnative fish management is vital, especially in years of low flow.	conditions and future management. • Efficacy of nonnative fish management is vital especially, in years of low flow.	population is vital; other problematic species are rare or absent. • Efficacy of nonnative fish management is vital especially in years of low flow.		• Yampa and Whirlpool Canyons not conducive to nonnative fish colonization. • Efficacy of nonnative fish management in the upstream Yampa River and the adjacent Green River is vital, especially in years of low flow.	• Temperature regulation device possible but assumed highly unlikely in a 16-year timeframe. • Ability to regulate warming important to prevent warm water nonnative establishment.
5. Suitable water quality	**Neutral—Uncertain** • Effects of persistent contaminants on Humpback Chub not well understood. • Emergency response plans and safety shutoff valves on pipelines will reduce threat.	**Neutral—Uncertain** • Effects of persistent contaminants on Humpback Chub not well understood. • Emergency response plans and safety shutoff valves on pipelines will reduce threat.	**Neutral—Uncertain** • Effects of persistent contaminants on Humpback Chub not well understood. • Emergency response plans and safety shutoff valves on pipelines will reduce threat.	**Neutral—Uncertain** • Effects of persistent contaminants on Humpback Chub not well understood. • Emergency response plans and safety shutoff valves on pipelines will reduce threat.	**Neutral—Uncertain** • Effects of persistent contaminants on Humpback Chub not well understood. • Emergency response plans and safety shutoff valves on pipelines will reduce threat.	**Neutral—Uncertain** • Effects of persistent contaminants on Humpback Chub not well understood. • Fish kills may continue in tributaries from ash-laden floods and debris flows after wild fires.
6. Unimpeded range and connectivity	**Good** • No impediment for movement to other populations in upper basin. • Fish passage at Price-Stubb, Grand Valley, Government Highline, and Redlands may expand upstream range.	**Good** • No impediment for movement to other populations in upper basin. • Fish passage at Price-Stubb, Grand Valley, Government Highline, and Redlands may expand upstream range.	**Good** • No impediment for movement to other populations in upper basin. • Fish passage at Tusher Wash may expand facilitate movement among populations.	**Good** • No impediment for movement to other populations in upper basin. • Fish passage at Price-Stubb, Grand Valley, Government Highline, Redlands, and Tusher Wash diversions may expand upstream range.	**Neutral** • No impediment for movement to other populations in upper basin, but population seems to distant from others to recolonize.	**Good** • Natural barriers in tributaries not expected to be modified for passage. • Translocations of young fish expected to continue.
7. Persistent population	**Good** • Population expected to continue to reproduce and recruit annually. • Management expected to continue to support populations. • Recent estimates indicate stabilization since 2007.	**Good** • Population expected to continue to reproduce and recruit annually. • Management expected to continue to support populations. • Recent estimates indicate stabilization since 2007.	**Fair** • Population expected to continue to reproduce and recruit annually. • Management expected to continue to support populations. • Evidence is insufficient to define population trajectory.	**Good** • Population expected to continue to reproduce and recruit annually. • Management expected to continue to support populations. • Population remained small but persistent since discovered in 1980.	**Neutral** • Translocation of fish from other populations may be successful in establishing a reproducing population. • Management expected to continue to support populations.	**Good** • Core Little Colorado River population expected to continue to reproduce and recruit annually. • Mainstem reproduction and recruitment expected with warmer water. • Range expansion expected with increasing numbers in mainstem and from tributary translocations.
8. High genetic diversity	**Good** • Genetic diversity expected to continue. • Exchange of fish with Westwater Canyon will continue to support genetic diversity.	**Good** • Genetic diversity expected to continue. • Exchange of fish with Black Rocks will continue to support genetic diversity.	**Fair** • Genetic diversity expected to continue. • Some loss of diversity may occur over long time period due to low exchange with other populations.	**Fair** • Genetic diversity expected to continue. • Some loss of diversity may occur over long time period due to low exchange with other populations.	**Neutral** • Translocation will support high genetic integrity in conjunction with population establishment. • Numbers of *Gila cypha* expected to remain low.	**Good** • Genetic diversity expected to continue. • Large reproducing populations in diverse habitats will continue to support genetic diversity.

[a] GCD = Glen Canyon Dam

6.0 SPECIES VIABILITY

6.1 Resiliency, Redundancy, and Representation

This assessment has so far described and evaluated species needs, current condition, and future condition of resources needed by the Humpback Chub. This section summarizes the importance of species-specific attributes in meeting the 3 R's (resiliency, redundancy, and representation) that together represent viability. Species-specific attributes are those inherent life history and genetic traits and characteristics that are important for coping with a variable and changing environment—in the present and into the future. These species attributes are the cornerstones of species viability, and are more fully described in sections 2.0 and 3.0. The species-specific attributes contribute to the conclusions developed for each of the three future scenarios presented in section 5 (see Tables 19 & 20 below).

6.1.1 Resiliency—Resiliency is the ability of individuals to withstand environmental or demographic stochasticity, as measured by species-specific traits and characteristics. The following are species-specific traits that enable individuals to be resilient in the face of environmental or demographic stochasticity:

1. ***Long life span:*** The Humpback Chub is a long-lived species, with some individuals living up to 40 years in the lower basin. This extended life span creates a storage effect with long-term survival of adults during adverse environmental conditions. The longevity allows individuals to persist through periods of drought and low flow, invasions of nonnative fishes, spills of toxic materials, and outbreaks of diseases and parasites, so that the few remaining individuals can rebuild the population during more suitable conditions.
2. ***High reproductive potential:*** The Humpback Chub lives for 20–40 years with the capability of spawning annually after the age of 4 or 5 years. Females produce ~2,500 eggs and spawn communally. This iteroparous reproductive strategy ensures that a large proportion of adults participate in spawning and that large numbers of eggs are produced. Evidence of skipped spawning has been seen in the Grand Canyon, which means that some adults may not spawn every year. This is evidently an energy conservation strategy to compensate for localized spawning movements, but it may also allow individuals to live longer and to build energy reserves for greater egg production.
3. ***Use of habitats arduous to other species:*** Humpback Chub are resilient to a variety of physical and chemical habitat conditions that are otherwise thought to be less suitable to other fish species. They inhabit deep canyon areas with swift flow. During spring runoff, flow in these canyons becomes turbulent with high velocity, and is laden with debris and turbidity. Many fish species are unable to cope with these conditions and are forced to leave. This defensive mechanism breaks down in low runoff years when conditions become less arduous and nonnative predators and competitors are able to invade these areas. Low runoff can also allow recolonization of native Roundtail Chub that compete and hybridize with Humpback Chub. In the LCR of the Grand Canyon, natural high total dissolved solids are unfavorable for

many fish species and serve to protect a principal spawning and nursery area of the Humpback Chub.

4. ***Wide flow range for life stages:*** The Humpback Chub appears to tolerate a wide range of river flows at all life stages. Upper basin populations have persisted through a wide range of historical and contemporary flows, and the population in Grand Canyon has experienced a dramatic change in the historical flow regime with the operation of Glen Canyon Dam. Yet, these populations appear to successfully complete their life cycles under these different flow regimes in different parts of the basin, albeit the Grand Canyon population relies very heavily, if not almost exclusively on the LCR for spawning and recruitment. However, a high and variable flow regime is needed to maintain channel diversity, stimulate food production, disadvantage nonnative predators and competitors, deliver episodic food supplies, and reduce abundance of competing and hybridizing Roundtail Chub. This hydrologic phenomenon occurs naturally in the upper basin, but is managed through dam operations and high-flow experiments in the Grand Canyon.
5. ***Wide temperature range for growth:*** The Humpback Chub is a warm-adapted fish that requires a narrow water temperature range of 16–22ºC for spawning and incubation. However, the species has a wide temperature range for growth of ~12–24ºC that allows individuals to inhabit areas with cool temperature. This adaptive trait is revealed with the contrast in water temperature in the Grand Canyon, where the species spawns primarily in the seasonally-warmed LCR, but resides in the cooler mainstem, where it has better health and greater longevity. The ability of the species to migrate annually to spawn in the warm LCR and retreat to the mainstem for possible post-spawn recovery and feeding appears to benefit the species and provide resiliency to individuals.
6. ***Variable and omnivorous diet:*** The Humpback Chub has a variable diet, such that individuals consume a large array of food items under different river conditions. This gives individuals a better chance of surviving catastrophes or periods of food shortage from a single source. Although the diet of larvae and age-0 Humpback Chub is fairly selective for diatoms and small invertebrates, older fish are less discriminating and capable of eating a large variety of foods. In the upper basin, the species has demonstrated an ability to consume invertebrates produced instream, as well as terrestrial and aerial insects, and animal and plant matter transported by large floods. In the Grand Canyon, a shift in diet from historical items to invertebrates produced in a post-dam era also demonstrates the resiliency of individuals to use available food items.
7. ***Use of turbidity for feeding and cover:*** The Humpback Chub is a high-turbidity adapted fish that is most active during episodic floods when the river is highly turbid and laden with a variety of animal and plant matter that is consumed as food. In the mainstem Colorado River in Grand Canyon, radio-tagged adults moved significantly greater distance and more often when turbidity was above 30 nephelometric turbidity units (NTUs); significantly greater movement at higher turbidity corresponded with higher gut content of food by adults (Valdez and Ryel 1995). Humpback Chub also appear to use turbidity as cover from potential predators. The vulnerability of juvenile Humpback Chub to predation by Rainbow Trout and Brown Trout was reduced with

increased turbidity in a laboratory setting (Paukert and Petersen 2007; Ward and Morton-Starner 2015), and higher turbidity corresponded with fewer feeding attempts by Rainbow Trout (as cited in Valdez and Ryel 1995). In Grand Canyon, turbidity may mediate piscivory by reducing prey detection, but Yard et al. (2011) found that Rainbow Trout piscivory was greater when suspended sediment levels were high (range = 5.9–20,000 mg/L). This may be attributed to a greater frequency of feeding forays by Humpback Chub during turbid conditions and thus, greater exposure to predation. Humpback Chub may have historically fed during turbid conditions—a time in which most food was delivered by floods—but the species may be naïve to avoiding nonnative predators.

6.1.2 Redundancy— Species redundancy is supported by multiple, resilient populations distributed across the range of the species. The following are species attributes that support redundancy of Humpback Chub at the population level.

1. ***Independent susceptibility to threats from basin-wide distribution***: The Humpback Chub is currently found as six populations over a range of ~1,353 km in five major rivers or segments of the Colorado River System (Green, Upper Colorado, Yampa, Lower Colorado, and Little Colorado rivers), each with independent susceptibility to threats. Only the Black Rocks and Westwater Canyon populations are in close proximity to share a common risk of threats. For the other populations, an area-specific threat (e.g., ash-laden flood, oil spill) cannot simultaneously affect multiple populations. The only threat that spans across the basin and affects these multiple populations is the potential effect of reduced water availability and specifically periods of drought, as seen during 1995–2002 (see section 4.5).
2. ***Large basin-wide number of individuals***: The total number of Humpback Chub in the Colorado River System is estimated at 16,000 adults, based on concurrent 2012 estimates. This includes ~3,800 adults in the upper basin and 12,250 adults in the lower basin (12,000 associated with the LCR and 250 in the mainstem). By comparison, at least one to two orders of magnitude greater numbers of sub-adults and juveniles and still greater numbers of larvae are produced, and their abundance may vary on an annual basis. Five of the six populations (except for DNM) reproduce on an annual basis, have persisted for decades since major system alterations (flows and invasive species), and support a cross-section of ages. A large number of adults and young in multiple and separate populations provides resiliency and redundancy.
3. ***Ability to sustain small populations in limited habitat:*** The Humpback Chub has an apparent ability to persist in relatively small areas. The smallest area occupied by a population is a 1.4-km reach of the upper Colorado River in Black Rocks. This population was first reported in 1975, and although the number of adults has varied by more than three-fold in 14 years, the population has demonstrated resiliency. Similar patterns of population oscillation have been seen with the Westwater Canyon and Desolation/Gray canyons populations over the same time period. Although population size is clearly a factor in resiliency and redundancy, the Humpback Chub is evidently able to persist with small numbers of individuals in limited habitat.

4. ***Apparent ability to recover from toxic spills:*** Altogether, large ash and debris-laden floods have negatively affected populations in Shinumo Creek, Desolation/Gray canyons, and Westwater Canyon, and petroleum spills have entered Desolation/Gray canyons and Yampa Canyon. The effects of these events on the Humpback Chub were not evaluated, but dead fish were observed and the populations have persisted.
5. ***Storage effect from long life span:*** Humpback Chub may live 20–40 years and adults of multiple ages provide a storage effect in years when there is little reproduction or recruitment. Individuals grow slowly after reaching maturity; therefore, lengths of fish of different ages overlap and age groups are indistinguishable after their fourth year of life. This large super-cohort of adults provides a buffer during years of poor environmental conditions when reproduction, survival, and recruitment are low. This age structure of adults not only provides a storage effect to ensure resiliency against catastrophic events, but also provides the population with a robust cross-section of sizes and ages that may be differentially resilient to internal and external population pressures and threats.
6. ***Demonstrated population recovery:*** The population of Humpback Chub in the Grand Canyon has shown a high level of resiliency with a decline in adults of ~54% over a 13-year period (1989–2001) followed by an increase of nearly 140% over a 12-year period (2001–2012) and an apparent stability to the present day. Estimates of abundance in upper basin populations are insufficient to detect this level of change, but numbers of adults have increased or decreased over time, illustrating that population sizes are variable and capable of responding to environmental conditions and management actions.
7. ***Ability to expand and translocate:*** The Humpback Chub has showed a high potential for redundancy through three successful translocations of individuals in the Grand Canyon: to the LCR above a series of falls; to Shinumo Creek; and to Havasu Creek. The fish in Shinumo Creek were killed or displaced by large ash and debris-laden floods, but the fish in Havasu Creek and in the LCR have reproduced. The species has also demonstrated an ability to naturally expand in distribution. Natural expansion has occurred in western Grand Canyon after Lake Mead receded and exposed the historical river channel once occupied by the species; Humpback Chub of various sizes and ages were found in 2014 and 2015 as a sign of expansion and possibly local reproduction. A similar expansion may be taking place in Cataract Canyon with receding levels of Lake Powell. Translocations of Humpback Chub to Grand Canyon tributaries have been successful and may be a viable strategy for population restoration or expansion in the upper basin.

8. ***Potential for additional reproducing populations:*** An important dimension of population redundancy in the Grand Canyon is the emerging evidence of successful reproduction in the mainstem and at least one additional tributary (Havasu Creek). Successful spawning outside of the LCR has a large effect on redundancy of the Humpback Chub in the lower basin. Continued reproductive success in one or more locations other than the LCR (e.g., mainstem in western Grand Canyon and Havasu Creek) minimizes the risk of losing a large part of the population to a catastrophic event and provides additional sources of naturally-produced fish.

6.1.3 Representation—Representation is the ability of a species to adapt to changing environmental conditions over time, as indicated by genetic and environmental diversity within and among populations. The following are attributes of Humpback Chub that support representation:

1. ***Ability to adjust to changing habitat condition:*** Physical habitat of the Humpback Chub in the upper basin has remained largely intact, except for changes in flow regime and invasions of nonnative plants that have had less effect on canyon areas than on alluvial reaches. Habitat in the Grand Canyon was altered by Glen Canyon Dam in 1963 and although flow, temperature, food supply, and sediment are altered, the geomorphic foundation is largely intact. The Humpback Chub in the Grand Canyon has shown a remarkable ability to adjust to these changing conditions and continues to be the largest population in existence.

2. ***Genetic diversity of populations maintained by small exchange of individuals:*** No natural exchange of individuals has occurred between upper and lower basin populations for over 50 years, since construction of Glen Canyon Dam in 1963. Limited exchange of individuals occurs among populations in the upper basin, and dispersal and mixing among fish in the LCR and the mainstem in Grand Canyon. Genetic analysis indicates a historically low level decadal exchange of individuals among populations that was sufficient to ensure genetic diversity. However, that level of exchange among upper basin populations is too low to provide demographic rescue, other than to possibly help maintain adult numbers in the smaller Black Rocks population as movement from the larger Westwater Canyon population.

   An important measure of genetic diversity is effective population size (N_e), which is a theoretical measure of the number of breeders in the population that contribute to genetic diversity. General guidelines for fish suggest that a population with N_e of 500 or greater has a low risk of losing genetically adaptive traits; whereas a population with 50 or fewer individuals is highly vulnerable to inbreeding depression and genetic drift (Allendorf et al. 1997; Reiman and Allendorf 2001). The computed N_e for the LCR population of 12,000 adults is 899–1,437 adults, which indicates that the N_e's for the current numbers of adults in Black Rocks (404), Westwater Canyon (1,315), Desolation/Gray canyons (1,672), and Cataract Canyon (295) are probably quite low. Nevertheless, these populations have persisted for over 20 years of monitoring, and maintained genetic diversity. The persistence of these small upper basin populations illustrates that the numbers of adults alone does not foretell population stability.

3. ***Use of different and diverse habitats:*** Humpback Chub in the Grand Canyon occupy habitats in the LCR and the mainstem Colorado River as part of their normal life cycle. These habitats are very different and diverse and demonstrate the adaptability of the fish to live in very different environments, even at a local scale. This trait also enables individuals to use a wide range of areas in the Grand Canyon as historical habitat becomes increasingly exposed with lowered levels of Lake Mead. Additionally, Humpback Chub have been successfully translocated into three tributaries (upper LCR, Havasu Creek, and Shinumo Creek) showing that they can live and reproduce in new environments.

6.2 Summary of Species Viability

Species viability is assessed within the context of the three future scenarios presented in section 5 over a biologically meaningful timeframe of two generation times or 16 years. For each scenario, an assessment of resiliency, redundancy and representation is presented based on each scenario's expected biological outcome. Both the species needs and the species-specific attributes listed above were considered in the assessment. For each scenario, we outline the possible biological outcome and elucidate the effects on resiliency, redundancy and representation (Table 20).

Scenario 1 [Environmental Stressors Increase and New or Discretionary Extralegal Actions are Eliminated] - includes an elimination of some active and adaptive actions, and a reduction in voluntary management actions for the species, such that many stakeholder actions are no longer in place to mitigate future conditions including decreased water availability, future water development, or nonnative fish. Without management action, we expect that the Dinosaur National Monument population will remain functionally extirpated with little hope of recovery. The population in Desolation/Gray canyons is likely to decline rapidly primarily because of an overwhelming influence of nonnative fish invasion. Individual Humpback Chub would be expected to remain in pockets throughout the canyon, but would not function as the current population does. It is possible that known nonnative predators, such as Walleye and Smallmouth Bass, would develop larger populations directly influencing Black Rocks and Westwater, likely threatening the resiliency of those populations. One or more additional population (in addition to DNM) would be expected to decline to functional extirpation. The Cataract and Grand Canyon populations would maintain higher resilience because the risk of invasion of nonnative predators in those areas is lower than other places in the upper Colorado River basin. Although the UCRRP is only authorized through 2023, stakeholders have indicated continued support for management of the endangered species in the Colorado River. Recent commitments (LTEMP) in the lower basin virtually guarantee future management of the Grand Canyon ecosystem.

Scenario 2 [Legally Mandated Management Actions and Additional Adaptive Management Actions Occur, but are Ineffective] - in addition to minimum actions required under Scenario 1, additional proactive and adaptive stakeholder agencies' management practices occur into the future for the species, but these actions are ineffective to mitigate impacts of drought, future water development, nonnative fishes, or other threats. Management action would encourage the repatriation of Dinosaur National Monument, though the resiliency of that population would remain under threat from nonnative predators, especially if management actions are insufficient to reduce nonnative populations. The Humpback Chub populations in Desolation/Gray canyons, Westwater and Black Rocks would likely receive additional pressure from nonnative predators/competitors and populations would continue to decline. Declines would be unlikely to remove populations within the 16-year time frame, but may over a longer time frame. Cataract Canyon and the Grand

Canyon populations would likely continue to fluctuate and represent the most resilient populations in the long term.

Scenario 3 [Legally Mandated Management Actions and Adaptive Management Actions Occur, and Are Effective] - in addition to minimum actions required under Scenario 1, additional proactive and adaptive stakeholder agencies' management practices occur into the future for the species, and these actions are sufficient to mitigate impacts of drought, future water development, nonnative fishes, or other threats. Management actions would be moderately likely to repatriate Dinosaur National Monument with continued management actions. The populations in Desolation/Gray canyons, Black Rocks and Westwater would fluctuate based on environmental carrying capacity, and would be likely to continue stabilization or increasing trends. Cataract and Grand Canyon populations would likely fluctuate over time.

It is apparent that the species is expected to be fairly well represented and resilient in the future under scenarios 2 and 3. Redundancy is less certain, but primarily because of the potential to see declines in upper basin populations under ineffective management actions. If management actions can prevent a loss of an additional upper basin population, or re-establish the Dinosaur National Monument population (Scenario 3), conditions will be sufficient for the species.

Using these conclusions to consider species viability, species experts and the Service agree that based on the best available information, species viability is more tenuous in the upper basin than in the lower basin. One of the largest threats to the Humpback Chub, that of nonnative fish invasions, increases dramatically with time as invasions are difficult to predict – both in timing and extent of damage. In both scenarios 1 and 2, the potential effects of nonnative predation or competition indicate that the species may suffer declines within the foreseeable future. Scenario 3 is defined by conservation programs' ability to react to and reduce the threat from these invasions, and thus shows species viability continuing on its current trend or possibly increasing over time.

Ongoing and future management could be sufficient to offset threats and promote survival and recruitment for 30 years, but uncertainty exists regarding future management activities. Although many conservation efforts in the Lower Basin are guaranteed for more than 50 years in the future, efforts in the Upper Basin have not been contracted beyond 2023 or funded beyond 2019. Uncertainty remains surrounding current population trajectories of Humpback Chub, densities of nonnative predators in the upper basin, and risk associated with future conditions throughout the basin.

Table 19. Predicted conditions for resiliency, redundancy, and representation in the upper basin relative to a biologically meaningful timeframe (2-generations; 16 years) under three possible future scenarios. Color codes: dark green = good; light green = fair; yellow = neutral; orange = poor; red = bad.

		Resiliency	Redundancy	Representation
Upper Basin	S1 – **Extralegal Adaptive Management Ceases**	**Bad** • Flow regimes no longer provide the inter- and intra-annual variability to support healthy Humpback Chub populations and preserve the historical balance with Roundtail Chub; Reclamation's Records of Decision at Flaming Gorge and Aspinall provide legal safeguard that would prevent catastrophic low flow. • Conditions become conducive to establishment of Smallmouth Bass and possibly other nonnative species. Nonnative predator densities increase throughout the upper basin and likely establish in Humpback Chub population centers. • Humpback Chub densities in all upper basin populations expected to decline quickly.	**Bad** • A DNM repatriation effort does not occur or is not successful. • One or more upper basin population is extirpated (most likely Deso/Gray; possibly Black Rocks) and the chances of repatriation are very low. • All other upper basin populations decline to levels that require intervention.	**Bad** • Genetic diversity and species adaptability throughout the upper basin could be irrevocably lost as populations are reduced below critical levels.
	S2 – **Extralegal Adaptive Management Continues, but prove Ineffective**	**Neutral** • Flow management is not adequate to support persistent Humpback Chub populations and percent composition of Roundtail Chub increases in all upper basin populations. • Smallmouth Bass and possibly unknown nonnative species exert greater predation and competition pressure (most likely in Desolation/Gray) despite fully implemented nonnative fish management strategy. • Humpback Chub densities in all upper basin populations are expected to decline gradually.	**Poor** • A DNM repatriation has a low probability of success. • Another upper basin population (most likely Desolation/Gray; possibly Black Rocks) declines to a level that requires intervention.	**Neutral** • Genetic diversity is compromised via population declines. • Site specific genetic management actions would be implemented and expected to succeed.
	S3 – **Extralegal Adaptive Management Continues and is Sufficient**	**Fair** • Flow management provides the inter- and intra-annual variability to support persistent Humpback Chub populations and preserve the historical balance with Roundtail Chub. Flow management preserves conditions that have precluded or limited establishment of Smallmouth Bass. • Nonnative fish management maintains conditions that limit establishment of known and unknown nonnative predators in Humpback Chub population centers. • Humpback Chub densities in all upper basin populations are expected to fluctuate around long-term, observed levels; and are expected to show periods of positive response in the near term (1 generation) in Black Rocks and Westwater Canyon.	**Fair** • A DNM repatriation has a moderate probability of success. • All four extant upper basin populations are expected to persist, maintaining redundancy.	**Fair** • Exchange of individuals between populations expected to continue. • Genetic diversity is preserved at current levels. • Hybridization with other *Gila* species expected to continue.

Table 20. Predicted conditions for resiliency, redundancy, and representation in the lower basin relative to a biologically meaningful timeframe (2-generations; 16 years) under three possible future scenarios. Color codes: dark green = good; light green = fair; yellow = neutral; orange = poor; red = bad.

		Resiliency	Redundancy	Representation
Lower Basin	S1 – **Extralegal Adaptive Management Ceases**	**Poor** • Management actions outside LTEMP to address additional habitat and nonnative stressors (including foodbase, parasites, pollutants etc.) unavailable. • Lowered Lake Powell elevations, further main channel warming and greater risk of establishment of nonnative predators. • Lack of rapid response outside the LCR aggregation could allow for establishment of nonnative predators. • Increases in nonnative predators could result in a significant decline in abundance.	**Neutral** • Increased populations of nonnative predators could affect Humpback Chub populations in the main channel outside the LCR aggregation; less of an effect in smaller tributaries.	**Fair** • Nonnative predators could diminish genetic exchange, population size and reduce genetic diversity.
	S2 – **Extralegal Adaptive Management Continues, but is Ineffective**	**Fair** • Management actions not fully effective at preventing risk from lowered Lake Powell elevations and further main channel warming, partially effective at responding to establishment of new or expansion of existing nonnative predators/competitors. • Populations likely plateau or contract.	**Fair** • Humpback Chub expansion and distribution reduced, but redundancy resulting from translocations remains	**Fair** • Genetic exchange throughout the lower basin populations is expected to continue, with or without effective management.
	S3 – **Extralegal Adaptive Management Continues and Effective**	**Good** • Strong commitment to effective prevention and response actions to address risks from lower Lake Powell elevations (warmer water and nonnative predators/competitors), and other stressors (food base, parasites, pollutants, etc.). • Greatest likelihood of population response - largest congregation of adults and largest storage effect.	**Good** • Humpback Chub geographic expansion continues (West Grand Canyon and additional translocations) providing increased redundancy.	**Good** • Genetic exchange throughout the LB populations expected to continue; current level of genetic diversity is high. Very low risk that genetic diversity would be compromised in this timeframe.

The Humpback Chub is a long-lived species that has persisted for more than three million years during periods of extreme environmental stochasticity. Five of the six populations have persisted for decades during modification of resource conditions, including four in the upper basin and one in the lower basin. Only the population in DNM is considered functionally extirpated; intervention will be necessary to restore this population, including stocking or translocation of fish along with ongoing flow and nonnative fish management. The population in Grand Canyon is the largest with fish distributed in two tributaries and in the Colorado River from 72 km downstream of Glen Canyon Dam to the Lake Mead inflow; increased numbers of different sizes indicate successful reproduction in the mainstem and a downstream expansion of the population. Of the four upper basin populations, adults in Black Rocks, Westwater Canyon, and Desolation/Gray canyons have declined in the last decade, but may have now stabilized. The Cataract Canyon population is small and persistent.

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APPENDIX A: Measures, Acronyms, and Abbreviations

The metric system is used for all units of measure in this document, except for cubic feet per second and river miles. Cubic feet per second (cfs) is the standard unit of measure used by the U.S. Geological Survey for surface-water data (http://waterdata.usgs.gov/usa/nwis/sw). River mile (RM) is a location on a given river, as measured upstream or downstream along the center of the river channel from a predetermined point (e.g., river confluence or compact point). The standard of river miles used in this document is from published Belknap's river guides available to the public for the Colorado River Basin, including: Canyonlands River Guide, Desolation River Guide, Dinosaur River Guide, and Grand Canyon River Guide.

The following is a list of acronyms and abbreviations used in this document:

ac-ft	acre feet
AGFD	Arizona Game and Fish Department
ASMRASMR	Age-Structured Mark-Recapture model
AZ	Arizona
BLM	Bureau of Land Management
C/m^2	Carbon per square meter
CFR	Code of Federal Regulations
cfs	cubic feet per second
CI	Confidence Interval
CNP	Canyonlands National Park
CPUE	Catch per unit effort
CROS	Coordinated Reservoir Operations
DNA	Deoxyribonucleic acid
DNM	Dinosaur National Monument
E	Ephemeroptera
EA	Environmental Assessment
ESA	Endangered Species Act of 1973
FEIS	Final Environmental Impact Statement
FONSI	Finding of No Significant Impact
FR	Federal Register
g/m^2	gram/meter squared
GCD	Glen Canyon Dam
GCDAMP	Glen Canyon Dam Adaptive Management Program
GCNP	Grand Canyon National Park
GCNRA	Glen Canyon National Recreation Area
GT	Generation time
HAZMAT	Hazardous Materials
IBM	Individual-based model

ISMP	Interagency Standardized Monitoring Program
KAF	thousand acre-feet
kg	kilograms
km	kilometer
LCR	Little Colorado River
LTEMP	Long-Term Experimental and Management Plan EIS
MAF	million acre-feet
mg/L	milligrams/Liter
mm	millimeters
msat	microsatellite genetic analysis
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
mtDNA	mitochondrial DNA
MVP	Minimum Viable Population
NASRF	J.W. Mumma Native Aquatic Species Restoration Facility
N_b	number of breeders in a population
N_c	census size
N_e	genetic effective population size
NP	Northern Pike
NPS	National Park Service
NS	Not sampled
NR	Not reported
P	Plecoptera
PBO	Programmatic Biological Opinion
P.L.	Public Law
PVA	Population Viability Analysis
Reclamation	Bureau of Reclamation
RK	River Kilometer
RM	River Mile
S	Survival rate
Service	U.S. Fish and Wildlife Service
SMB	Smallmouth Bass
SNARRC	Southwestern Native Aquatic Resources and Recovery Center
Spp	Species
SR	State Road
SSA	Species Status Assessment
STReaMS	Species Tagging Research and Monitoring System
T	Tricoptera
TL	Total length

UCRRP	Upper Colorado River Endangered Fish Recovery Program
UDWR	Utah Division of Wildlife Resources
U.S.C.	United States Code
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
TDS	Total Dissolved Solids
WE	Walleye
WS	White Sucker
°C	degrees Celsius
°F	degrees Fahrenheit

APPENDIX B: Stream Flow and Temperature Predictions

B.1 Basin-Wide Projections—The future condition of the Humpback Chub is driven largely by environmental factors linked primarily to flow and temperature. Flow and temperature of the Colorado River System have been influenced for the last century by human activities that have regulated hydrology basin-wide and altered river temperature in short reaches below impoundments. This reduced flow and altered temperature have been exacerbated in the last 5–6 decades by periods of drought. These periods are marked by reduced stream flow and increased air temperature and evaporation that are likely to continue and result in a number of ecological consequences, including, but not limited to reduced habitat availability, increased abundance and expansion of nonnative predaceous and competitive fish species, altered food supplies, and shifts in reproductive timing.

To examine future environmental condition for the Humpback Chub, it is important to set the stage with a characterization of historical and recent hydrology for the Colorado River System. Seven reconstructions of the Colorado River annual flow at Lees Ferry (Colorado Water Conservation Board 2012), based on calibration of tree-ring data, show that over a 500-year period (1492 to 1992), flow has varied by over 200% in approximately 20 to 60-year cycles (Figure 25). These reconstructions show that most recently, the Colorado River has been in a high-flow cycle until the mid-1980s, at which time a regional drought began that has lasted for over 30 years. The reconstructions illustrate the wide range of historical low and high water volumes (~8–19 MAF), as well as the uncertainty behind the future hydrology of the Colorado River. Recent possible manifestations of reduced water availability add to the uncertainty of river flow and associated environmental conditions that affect the Humpback Chub.

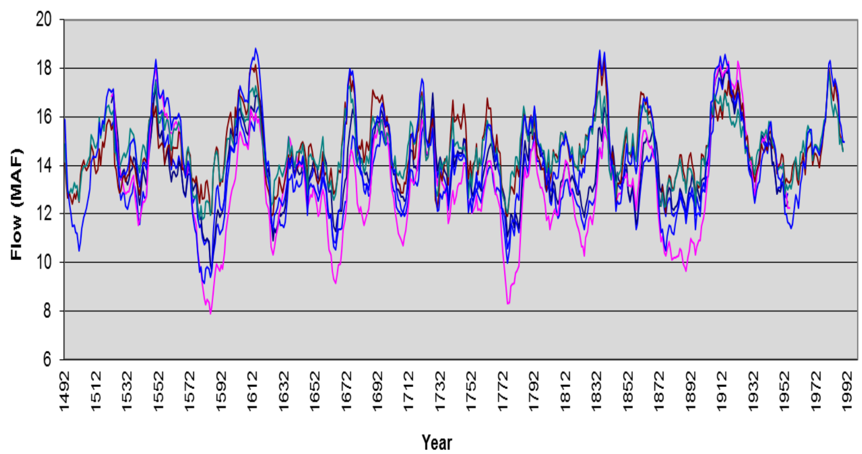


Figure 1. Seven reconstructions of Colorado River annual flow (as million acre-feet, MAF) at Lees Ferry, using tree-ring data. Source: Colorado Water Conservation Board (2012).

Recent and ongoing drought throughout the Colorado River System has resulted in increased air temperature and evaporation, despite a relatively stable annual precipitation (Figure 26; Christensen et al. 2004). Average air temperature in the U.S. has increased by 1.3°F to 1.9°F since record keeping began in 1895; most of this increase has occurred since ~1970 (Melillo et al., 2014). The Western U.S. has warmed roughly 2°F and is projected to warm further during the 21st century (Reclamation 2016). Based on data available from the Western Climate Mapping Initiative, the change in 11-year annual mean air temperature during the 20th century is roughly +1.2°C (2.16 °F) for the upper basin and +1.7 °C (+3.06 °F) for the lower basin. Projected annual evaporation increases are typically around 2 to 6 inches by 2080 at most western reservoirs, including Lake Powell and Lake Mead.

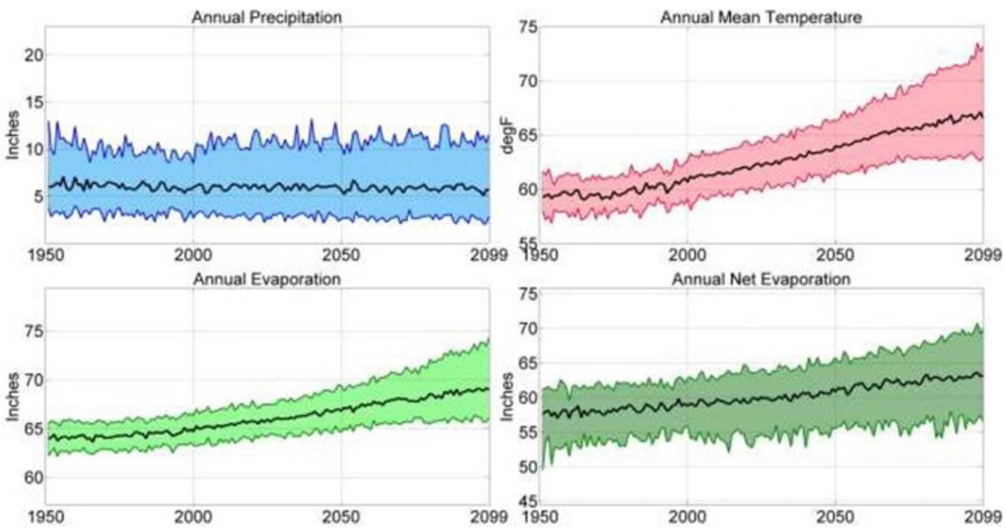


Figure 2. Projections for the Colorado River System (Lake Powell) of annual precipitation, temperature, reservoir evaporation, and net evaporation. The heavy black line is the annual time series of 50 percentile values. The shaded area is the annual time series of 5th to 95th percentiles. Source: Reclamation (2016), Figure 2-8.

A time-series plot of annual flow volume for Lees Ferry (1890–2004) and Lake Powell inflows reveals a decadal decrease of ~7.5% (Figure 27). This downward trend in stream flow volume of the Colorado River is not explained solely by increased air temperature and evaporation. It is also linked to the sensitivity of the snowpack accumulation process that dominates the spring runoff, and to a high and increasing water demand relative to supply (Rasmussen et al. 2014). One notable trend in hydrology is reduced winter snowpack with a shift in precipitation from winter to early spring. This shift has resulted in late winter and early spring precipitation occurring primarily as a snow/rain mix with immediate runoff and less snowpack accumulation. Highest precipitation levels now occur in spring with peak stream flow having shifted from June to May and lower stream flow in summer and fall.

In summary, projected basin-wide precipitation is not expected to change appreciably over the next 75 years, but because of increasing air temperature and evaporation, stream flow is expected to decrease.

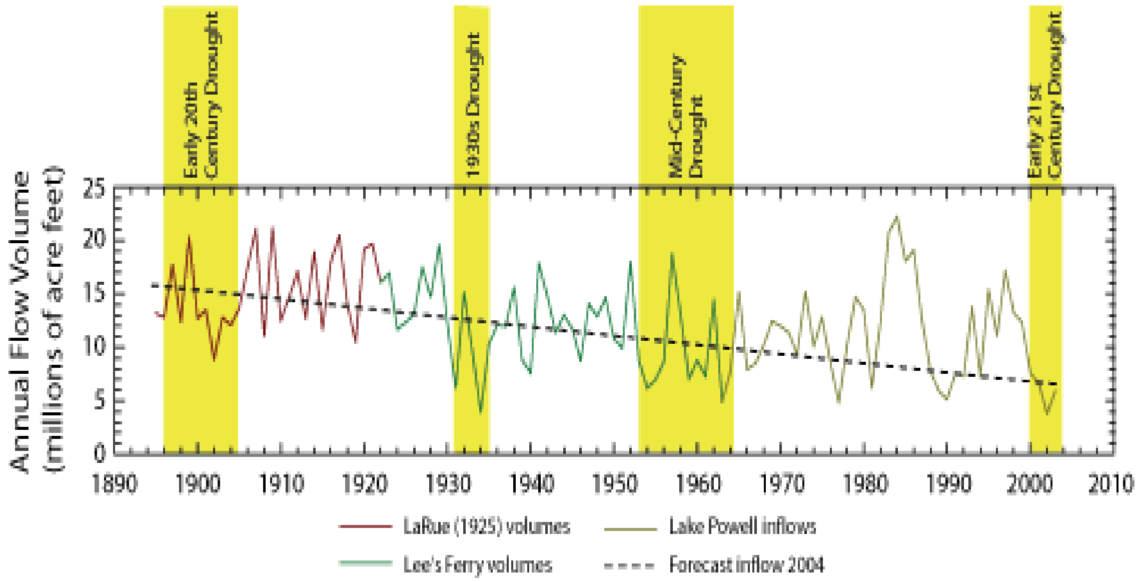


Figure 3. Time-series plot of the annual flow volume (in millions of acre-feet) at Lees Ferry and Lake Powell inflows. Dashed line is the linear trend for the period. Vertical bars and shading delineate drought periods as defined by the Palmer Drought Severity Index for the climate divisions encompassing the upper Colorado River basin. Source: http://pubs.usgs.gov/fs/2004/3062/.

B.2 Upper Basin—The populations of Humpback Chub in the upper basin have each changed trajectory in adult abundance during the period of monitoring (see section 6.1). These changes in intrinsic growth are driven largely by reproductive success, survival, and recruitment that are linked to a complexity of environmental factors. These linkages are not well understood, but apparent correlations suggest possible causation related primarily to stream flow. Additional monitoring and research are needed to better understand these relationships and causations.

Relationship of Stream Flow to Adult Humpback Chub Abundance—An examination of the hydrograph of the Colorado River at Stateline shows that flow magnitude, represented as maximum daily flow by year, declined steadily from ~50,000 cfs in 1995 to ~5,000 cfs in 2002, or a 90% decrease over a 7-year period; maximum daily flow in 2002 was the lowest in 26 years (Figure 28A). After 2002, maximum daily flow remained stable, except for the low of 2012. Overall trend in flow for 17 years (1995–2015) was a slight but insignificant decline ($p = 0.3671$), while declines in adult Humpback Chub in Black Rocks and Westwater Canyon were significant ($p = 0.0014$ and 0.0015, respectively).

A similar analysis was done for the Green River and adult abundance in Desolation/Gray canyons (Figure 28B). Maximum daily flow in the Green River decreased from ~30,000 cfs in 1995 to ~9,000 cfs in 2002, or ~70% decline. Although flow decline in the Green River occurred about the same time as on the Colorado River (1995–2002), abundance estimates of

Humpback Chub were not available for that time, but an apparent decline in adults occurred during 2006–2015, though not significant ($p = 0.2537$).

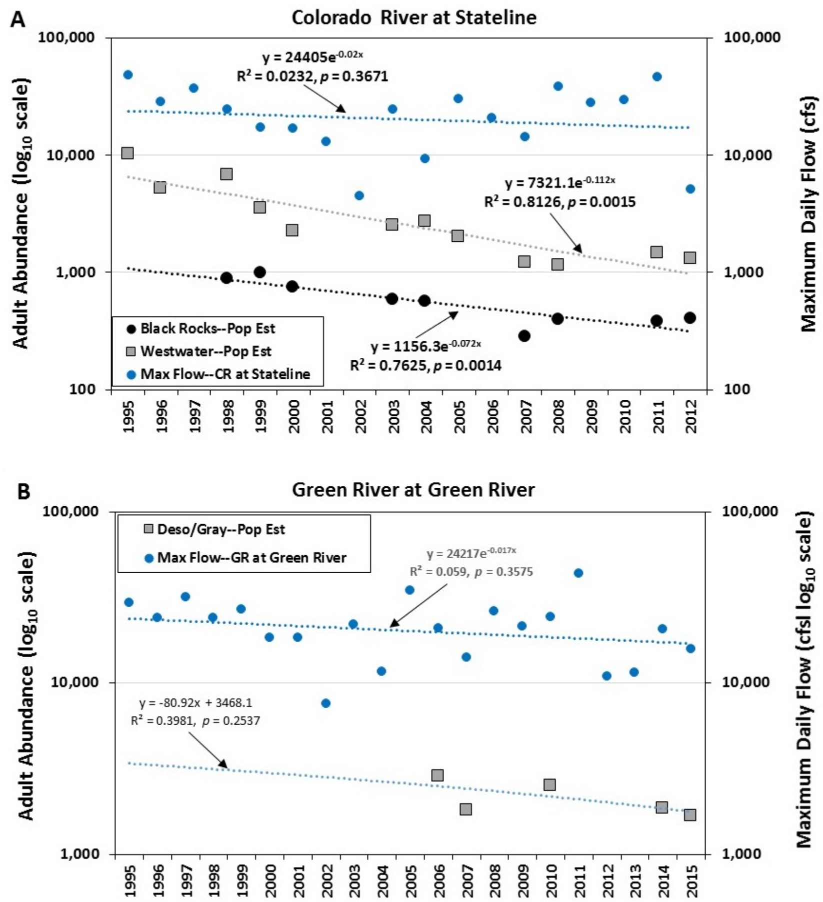


Figure 4. (A) Abundance of adult Humpback Chub in Black Rocks and Westwater Canyon, and maximum daily flow by year of the Colorado River at Stateline, CO (USGS 09163500) for 1995–2012; and (B) abundances of adult Humpback Chub in Desolation/Gray canyons, and maximum daily flow of the Green River at Green, UT (USGS 09315000) for 1995–2015.

A closer examination of these data illustrates how the decline in adult abundance was correlated to a decline in maximum flow for 1995–2002 in Black Rocks and Westwater Canyon (Figure 29). We hypothesize that the 7-year period of flow decline set the stage for the continued decline of these populations through reduced reproductive success, habitat, and food supply, as well as invasions of predaceous and competing fishes. The effect on adult abundance of Humpback Chub was seen 3 years after the low flow occurred, or about the time that fish recruit to the adult portion of the population.

According to Francis et al. (2016), the decline in Black Rocks adults from 1998 to 2007 was the result of relatively low adult survival and insufficient recruitment to replace adult mortality. Low adult survival was attributed to low river flow from drought and consequent ecological effects; whereas low recruitment was attributed to poor reproductive success and to predation of young fish by nonnative fish. A nearly identical pattern of peak flow and fish abundance was seen in Westwater Canyon for 1995–2002, and a similar conclusion was reached by Hines et al. (2016) for the decline in adult abundance in that population. These analyses indicate that consecutive years of low spring flow are responsible for periodic declines in abundance of Humpback Chub in upper basin populations.

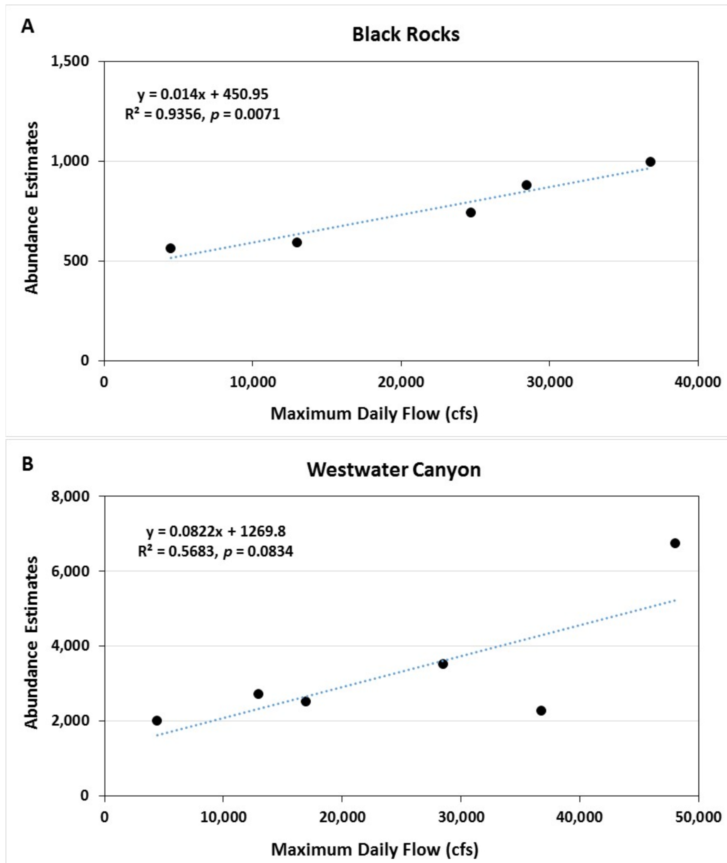


Figure 5. Adult abundance of Humpback Chub in (A) Black Rocks and (B) Westwater Canyon, correlated to maximum daily flow by year for the Colorado River at Stateline, CO (USGS 09163500) for 1995–2002. Adult abundance is correlated to river flow 3 years prior.

Relationship of Stream Flow to Adult Roundtail Chub Abundance—The low survival of adult Humpback Chub during periods of low spring flow may also be linked to higher numbers of Roundtail Chub that compete for food, space, and spawning habitat (that may result in hybridization). Inverse relationships were seen in Black Rocks and Westwater Canyon between adult Humpback Chub abundance and adult Roundtail Chub catch per unit effort (CPUE; Figure 30). In the period when maximum daily flow declined during 1995–2002, the density of Roundtail Chub increased as the number of adult Humpback Chub decreased in both populations. The mechanism behind this reduction is unclear, but is evidently linked to carrying capacity and competition with Roundtail Chub—as well as invasive nonnative fishes. This analysis indicates that annual change in flow magnitude may not have much effect on Humpback Chub populations, as long as periodic high flows occur. However, as observed for 1995–2002, a persistent period of low flow apparently has a detrimental effect on populations by resulting in consecutive years of reduced adult survival and poor reproductive success with subsequent poor recruitment.

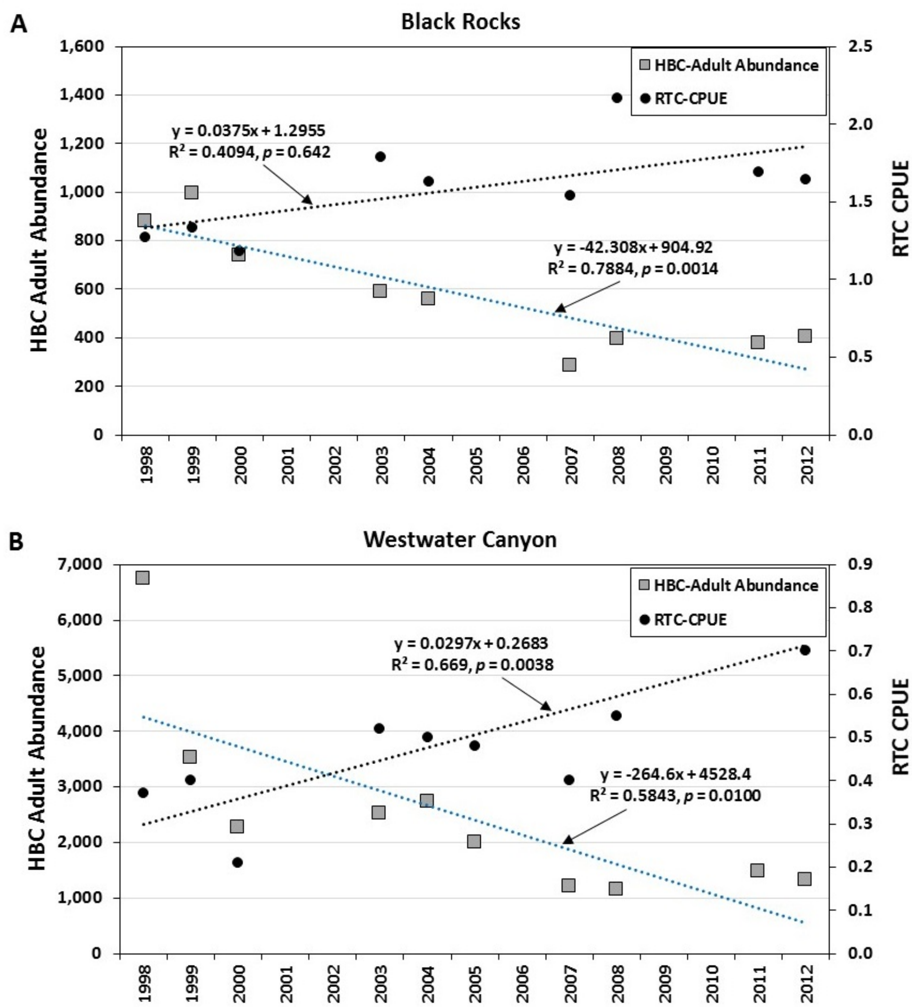


Figure 6. Adult abundance of Humpback Chub (HBC) and CPUE of Roundtail Chub (RTC) in (A) Black Rocks and (B) Westwater Canyon for 1995–2012.

Relationship between Stream Flow and Nonnative Fish--The abundance of nonnative fish differs with population in the upper basin (see section 4.1.4). Annual catch rate data from the Interagency Standardized Monitoring Program show the lower densities of nonnative fish and higher densities of Roundtail Chub in Black Rocks and the opposite condition in Desolation/Gray canyons (Figure 31). We hypothesize that invasion of these species is largely related to episodes of good Smallmouth Bass production in upstream areas during low spring peak flow. Influxes of juvenile Smallmouth Bass have been detected in Desolation and in the DNM population centers during low flow years, but densities typically drop off during wetter hydrologies. Smallmouth Bass have never been detected in appreciable numbers in Black Rocks, Westwater, and Cataract canyons, although they do exist in higher densities nearby in Ruby-Horsethief Canyon, the Grand Valley, and Lake

Powell. These relationships foretell a future effect of drought on the upper basin Humpback Chub populations, and on the future effect of nonnative fish and Roundtail Chub. It should be noted that past and recent genetic analyses indicate that hybridization and introgression are part of the evolutionary history of the Humpback Chub and are not expected to have a long-term effect on genetic diversity. However, a large number of Roundtail Chub in these confined population centers could impose sufficient competition to negatively affect Humpback Chub survival and subsequent recruitment.

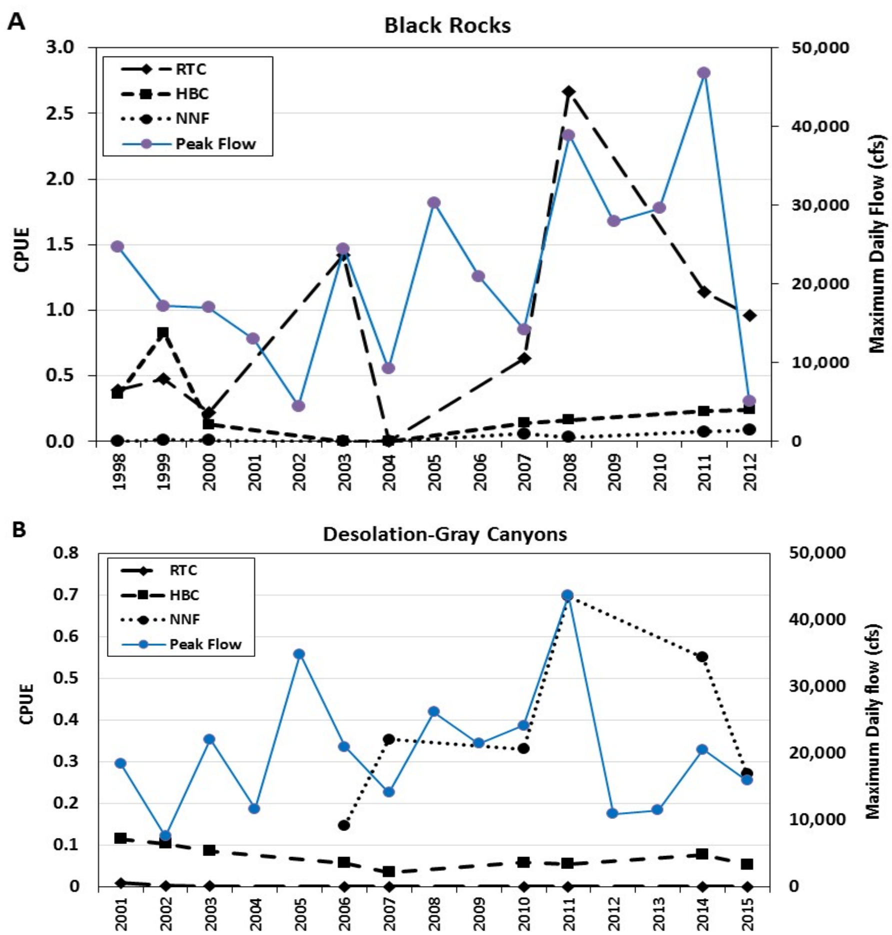


Figure 7. CPUE of Roundtail Chub (RTC), Humpback Chub (HBC), and nonnative fish (NNF) in (A) Black Rocks, 1998–2012, and (B) Desolation/Gray canyons, 2001–2015, compared to 3 years prior maximum daily flow for the Colorado River at Stateline, CO (USGS 09163500), and Green River at Green River, UT (USGS #09315000), respectively.

The most striking example of nonnative fish response to low stream flow was seen in the Yampa River during 1997–2002, when annual maximum daily flow dropped from 16,400 cfs to 3,420 cfs (Figure 32). Unfortunately this drought was coincident with a large release of Smallmouth Bass from Elkhead Reservoir (located in the Upper Yampa River drainage) when the reservoir was drained for dam repairs. The lowest daily flow of the Yampa River in 100 years of record occurred in August of 2002 at 1.8 cfs near Maybell; a flow of 2 cfs had been recorded in 1934. Density of Smallmouth Bass increased as the flow declined and conditions became suitable for spawning and survival of young. The population continued to increase to 2005 and declined thereafter as the result of an intensive bass removal program and a return to a wetter hydrology. Although flow in the Yampa River has resumed pre-drought level, Smallmouth Bass have persisted in the middle reaches of the Yampa River and mechanical removal continues as a strategy to manage the numbers of this invasive species (see section 5.4). This demonstrates how a nonnative fish species can take hold and how difficult it can be to reduce its numbers even after environmental conditions are more suitable for native fish species.

The decline of the Humpback Chub population in DNM apparently started with completion of Flaming Gorge Dam on the Green River in 1962, the associated rotenone treatment, and the effect of cold dam releases through Lodore and Whirlpool canyons. Forty years later Smallmouth Bass joined the existing suite of nonnative species and increased in number and distribution through the Green River subbasin. Main production zones for Smallmouth Bass in the Yampa River are immediately upstream of Yampa Canyon. Yampa Canyon experiences influxes of young Smallmouth Bass from those upstream spawning areas during years of good production (typically low water years). Those influxes undoubtedly have some impact on the native fish community of Yampa Canyon including Humpback Chub, but the native fish community has remained robust, with native sucker comprising the bulk of the fish community within the canyon.

This is the same mechanism that is believed to have taken place in Black Rocks and Westwater Canyon during 1995–2002, when extremely low flows for 4–7 consecutive years negatively impacted the Humpback Chub population. Fortunately, Smallmouth Bass are rarely encountered in these canyon reaches, despite occurring nearby in other portions of Ruby-Horsethief Canyon.

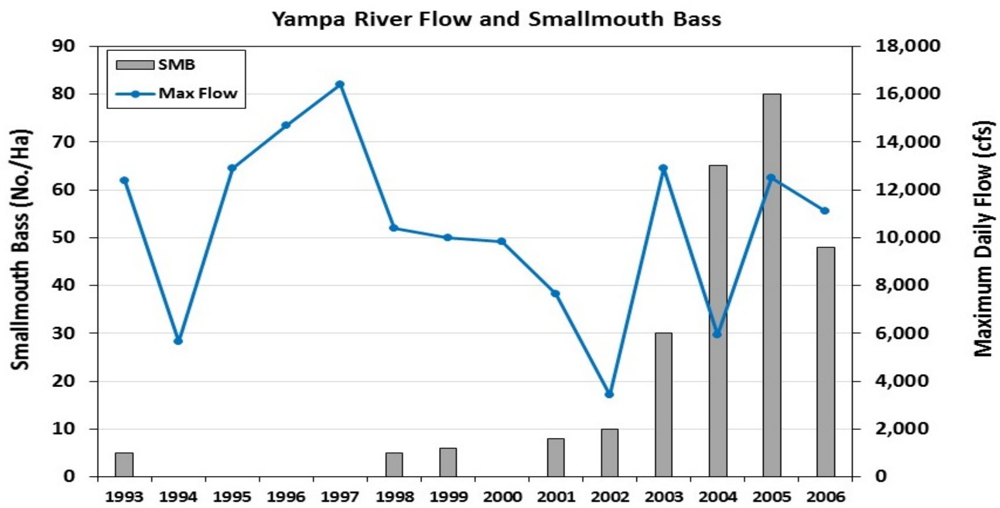


Figure 8. Decline in maximum daily flow of the Yampa River near Maybell, CO (USGS 09251000) for 1997–2002 and the corresponding increase in juvenile Smallmouth Bass (SMB) produced upstream. Density of Smallmouth Bass from Haines and Modde (2002). Large scale removal of Smallmouth Bass in the upstream Yampa River was initiated in the late 2000s.

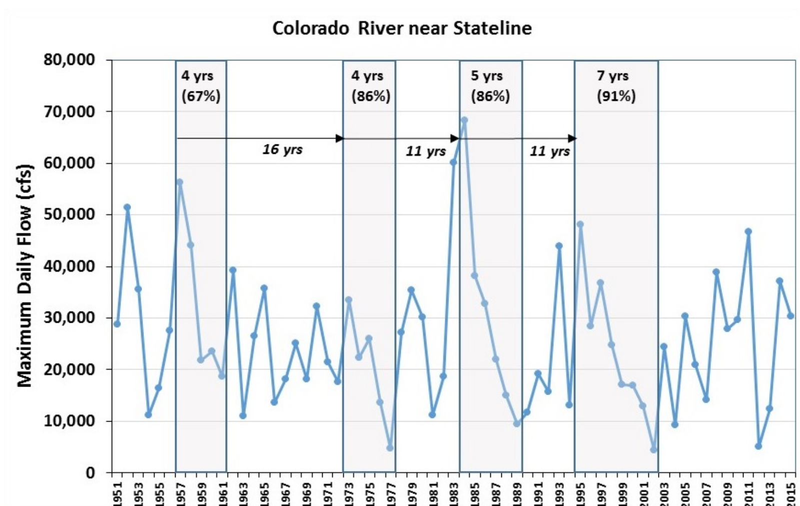
Frequency of Drought Episodes—Estimates of Humpback Chub adult abundance are available for upper basin populations only after 1995, and it is possible to link population decline with only one drought episode, 1995–2002. This episode affected the flow of all upper basin streams with a simultaneous decline in flow magnitude in the Upper Colorado, Green, and Yampa rivers. If the linkage described above between flow magnitude and Humpback Chub abundance is correct, one prediction is that downward population trajectory will be linked to episodes of drought 4–7 years in duration, and that stable or upward trajectory will be linked to wetter periods.

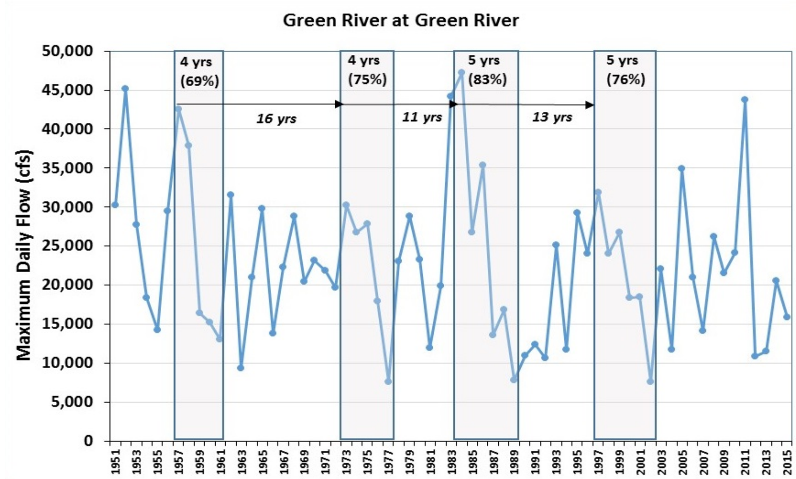
Four such episodes of drought (4–7 years duration) have occurred in the upper basin in the last 64 years, spaced 11–16 years apart (Figure 33). These episodes correspond to periods of low flow following peak flows of 1957, 1973, 1984, and 1995 (see Figure 27). Evidently, the upper basin populations have persisted through prior episodes of drought, but the presence of nonnative fish, especially the more recent predaceous forms like Smallmouth Bass and Walleye, have evidently exacerbated these conditions. If nonnative fish are capable of increasing in abundance within population centers, it becomes a foregone conclusion that predation and competition will suppress Humpback Chub populations during these drought episodes, and possibly beyond, depending on how established certain nonnative species can become. Based on hydrological regimes presented in Figure 33, there is a 1 in 16 chance (6%) for the recurrence of a drought episode as previously described, with perhaps increased probability during extended drought.

The Humpback Chub in the upper basin appears to do well under the normal range of flows for the Colorado River, and periodic high flows appear to benefit the species by providing suitable conditions that result in strong year classes. However, episodic droughts stress canyon ecosystems, reduce survival and recruitment, and allow invasions of nonnative fish and competing Roundtail Chub. This condition is exacerbated by the persistence of nonnative predators, where an otherwise exceptionally high flow is required to limit their abundance in canyon-bound population centers.

The larger populations of Humpback Chub are clearly more resistant and resilient to these drought episodes because of the greater number of long-lived adults that provide storage of reproductive potential. The viability of the Humpback Chub in the upper basin will depend on the efficacy of flow management to moderate low flows during drought; as well as the efficacy of nonnative fish management to adequately control predators and competitors.

These relationships of flow to abundances of Humpback Chub, Roundtail Chub, and nonnative fish allow us to provide some reasonable projection of future Humpback Chub populations, given the current understanding of upper basin hydrology. Past hydrology, as shown in Figures 25 and 27, indicates that periodic episodes of drought are likely to reoccur. Knowing these relationships empowers managers to anticipate and offset periods of low flow, and accelerate efforts to regulate nonnative fish so that they don't expand into in Humpback Chub population centers, especially during years of low flow.





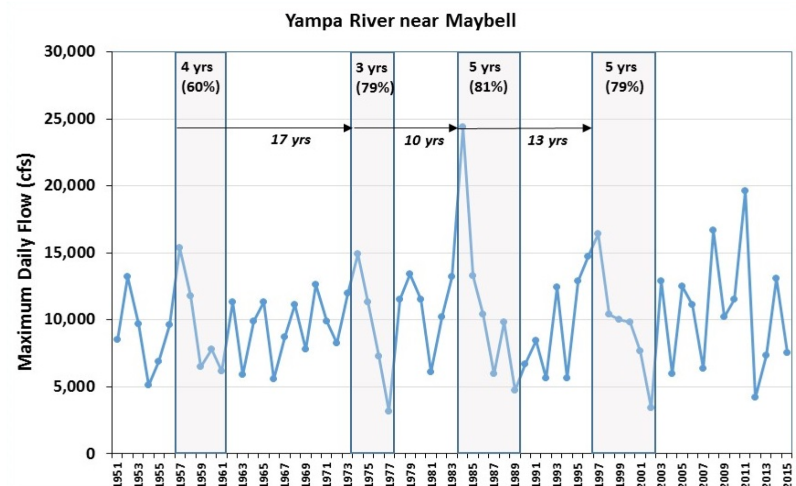


Figure 9. Maximum daily flow by year for 1951–2015 for the Colorado River near Stateline (USGS 09163500), Green River at Green River (USGS 09315000), and Yampa River near Maybell (USGS 09251000). Episodes of declining flow magnitude are highlighted by gray vertical bands with duration of each episode and percent decrease in peak flow indicated.

B.3 Lower Basin—The flow relationships analyses done in the upper basin were not done for Humpback Chub in the Grand Canyon, where flow is controlled within a predicable range, and the complexity of natural environmental correlates is confounded by multiple altered resources. Furthermore, investigations show that the species is affected differently in the LCR and in the mainstem Colorado River. Coggins et al. (2006) and Coggins (2008) explored prior survival and recruitment rates that led to the adult decline from 1989 to 2001, as well as to the increase in numbers after 2001 (see section 4.5.6), and determined that the population was driven by an interaction of flow, water temperature, food supply, and nonnative predators and competitors in the two systems.

Valdez and Ryel (1995) determined that production of age-0 Humpback Chub in the LCR, and subsequent recruitment to the mainstem, was driven by high spring flows in the LCR, as observed for a strong 1993 year class after a high flow, but that predation by Rainbow Trout and Brown Trout in the mainstem could eliminate an entire year class. VanHaverbeke et al. (2013) found a strong correlation between spring runoff for 2000–2012 in the LCR and fall age-0 CPUE ($n = 13$, $r = 0.755$, $p = 0.003$), which translated to high numbers in the mainstem (Finch 2012). Valdez and Kubly (2013) determined that average maximum daily discharge of the LCR for the period 1988–2000 was the lowest on record, which apparently led to low reproductive success and contributed to the 1989–2001 adult decline. Hence, as with the prior analysis of peak flow for the upper basin, the same phenomena was observed in the LCR, where production of Humpback Chub was linked to high spring flow.

Factors that affect the Humpback Chub population in the mainstem Colorado River differ from those of the LCR, primarily because the mainstem is a larger river system with cool water from dam releases. Dzul et al. (2017) developed a Bayesian state-space growth model to assess effects of temperature, turbidity, food availability, flow variability, and trout abundance on subadult Humpback Chub growth in the Colorado River and the LCR, by using out-of-sample prediction to rank competing models. Environmental covariates explained a high proportion of the variation in growth in both rivers; however, the best growth models were river-specific and included positive temperature and turbidity duration effects for the Colorado River and positive temperature and food availability effects for the LCR. These results quantify and confirm earlier observations by investigators related to the benefits of temperature (e.g., Coggins 2008; Finch 2012) and duration of turbidity (e.g., Valdez and Ryel 1995; Ward and Morton-Starner 2015) to juvenile Humpback Chub.

While the best Colorado River model included temperature and turbidity duration effects, it did not include effects of food availability, trout, and flow variability on subadult Humpback Chub growth. Importantly, the food availability metric did not include allochthonous inputs, which are an important source of food during flood events. Although neither trout nor food effects were included in the top model, the second model included a negative trout effect and a positive food effect, lending support to the hypothesis that trout compete with Humpback Chub. Trout abundance may affect food availability and thus exert indirect, long-term effects on chub growth that are difficult to detect (Dzul et al. 2017).

In the LCR, Dzul et al. (2017) also found that growth was highest when food availability was high but temperatures were moderate; i.e., 18°C is below the optimal growth temperature for Humpback Chub. The sparse data on food availability suggest a synchronous timing of high invertebrate emergence and high Humpback Chub growth rates. Furthermore, because the food availability metric did not include food items such as fish, larvae, or eggs, it may underestimate food availability in April and May when egg and larval production are at their peak and Humpback Chub have displayed cannibalism (Gorman and Stone 1999). Dzul et al. (2017) did not find an effect of turbidity on growth in the LCR, as reported earlier by Dzul et al. (2016).

The future condition of the Humpback Chub in the Grand Canyon appears favorable, but is clearly affected by a suite of variables with different interactions in the LCR and the mainstem, that lend some uncertainty to annual reproduction, survival, and recruitment. The following is a summary of the future condition of these variables and their likely effect on fish populations.

Relationship of Lake Powell Elevation to Dam Release Temperature— Temperature of the Colorado River through the Grand Canyon is influenced by Lake Powell inflow and elevation, temperature and volume of dam releases, time of year, and longitudinal downstream river warming. The hydrologic analysis for the LTEMP EIS was used to help assess future temperature for the Colorado River through Grand Canyon (U.S. Department of the Interior 2016, Appendix D: Hydrology Technical Information and Analysis). Projected temperature was derived from 21 traces each for 20 years (CY 2014-2033) at the confluence of the LCR (RM 62; Figure 34).

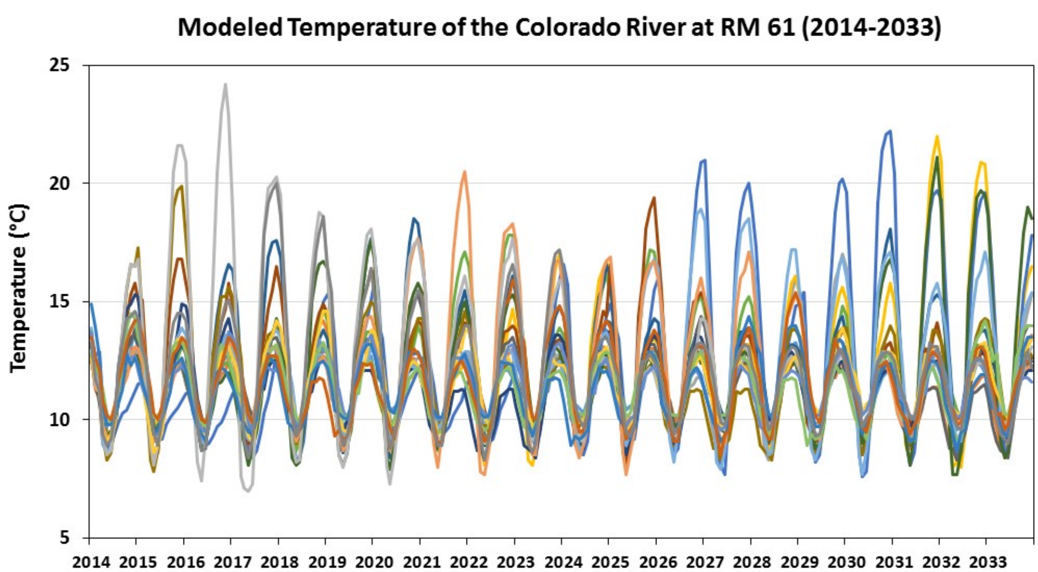


Figure 10. Projected mean monthly temperature of the Colorado River at RM 61, based on 21 traces each for 20 years (CY 2014-2033). Source: GCMRC; see U.S. Department of the Interior 2016, Appendix D: Hydrology Technical Information and Analysis.

A temperature duration curve for each of the years in the traces, as the sum of mean monthly temperature, was used to help identify the percent of time that a given temperature regime was likely to be equaled or exceeded in the future (Figure 35). The 25%, 50%, and 75% exceedance values were used to select a representative year for an analysis of future temperature and possible fish response with respect to timing of spawning.

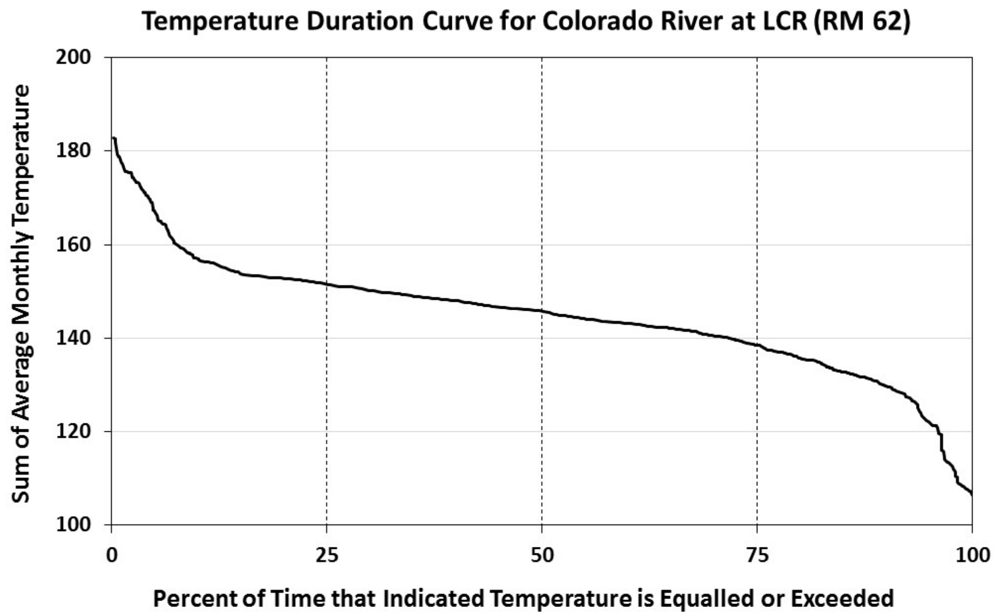


Figure 11. Temperature duration curve for the Colorado River at RM 62 (immediately downstream of the Little Colorado River). Curve is based on the sum of average monthly temperature for each of the years represented in Figure 33.

The annual thermographs are provided to illustrate the temperature for a pre-dam year (1960) and for representative years equal to 25%, 50%, and 75% exceedance for the Colorado River at Lees Ferry (RM 0), and immediately downstream of the LCR (RM 62), Havasu Creek (RM 157), and Diamond Creek (RM 226; Figure 36). River temperature at the various locations was determined with a model developed by Wright et al. (2008) that accounts for air temperature, water volume, time of year, and distance downstream.

The pre-dam thermograph characteristically peaked at ~25°C in July and dropped to near-freezing temperatures in January and December. The post-dam projected thermographs all indicate minimum temperatures of ~8–10°C from January to April upstream of the LCR. The thermograph equal to 25% exceedance is the warmest with maximum temperatures of 15, 16, 17, and 20°C in late August and early September at the four locations, respectively. The year of 50% exceedance is colder with maxima of 13, 14, 16, and 17°C, respectively, in October and November. For the most likely future thermograph at 75% exceedance, maximum temperatures of 11, 13, 15, and 17°C, respectively, are reached in August and September.

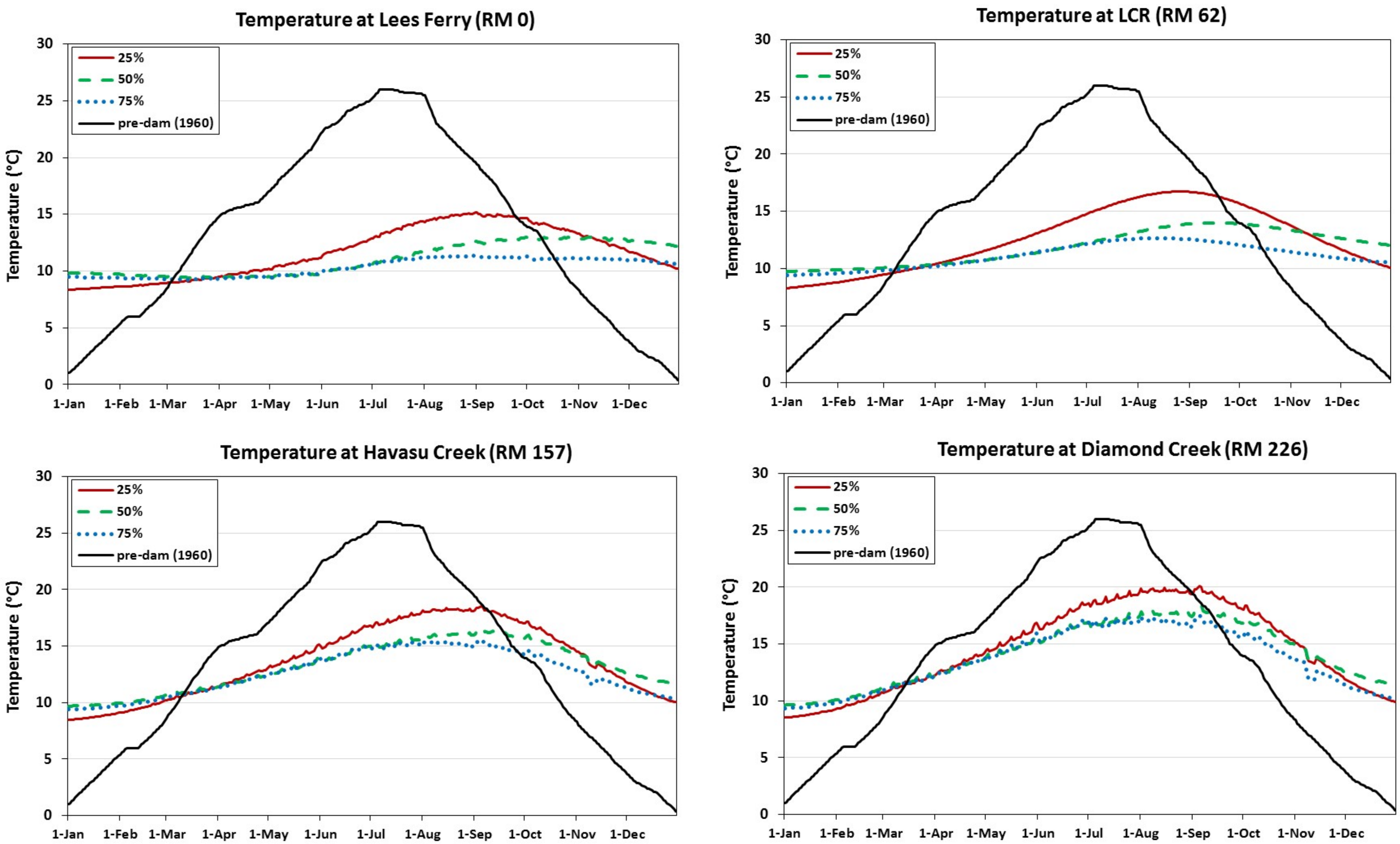


Figure 12. Colorado River temperature at Lees Ferry, and immediately downstream of the LCR, Havasu Creek, and Diamond Creek for pre-dam (1960), and representative years equal to 25%, 50%, and 75% exceedance of projected temperature.

This modeling shows that dam release temperature, even at low reservoir elevation, does not reach a maximum level until August to October, unlike the earlier pre-dam peak of July. This phenomenon of warmest releases in fall is caused by mixing during fall overturn; i.e., as the surface of the reservoir cools, the relatively warm water sinks and becomes entrained in the penstocks.

Warm dam releases occur earlier if the reservoir is low; however, lake elevation must be maintained at least 40 feet over the penstock elevation of 3,470 feet to avoid air entrainment and cavitation that impedes power generation, and the warmest surface water from the reservoir is not likely to become entrained. Another aspect of the post-dam thermograph is that water released from the dam and at downstream locations does not drop below ~7°C, and it never freezes as occurred during pre-dam flows.

Projected Response by Fish to Dam Release Temperature—The response by selected fish species of Grand Canyon to projected future river temperatures was evaluated with a temperature degree-day (TDD) model (Valdez et al. 2013). The model computes TDD by calendar year and compares the computed TDDs with estimated minimum TDDs required by species for spawning, incubation, and growth. This comparison provides a determination of whether one or more of these life stages is possible for a given annual thermograph and the dates in which the TDDs are met.

For the Humpback Chub, suitable TDDs for spawning occurred under pre-dam conditions during the month of April throughout the Grand Canyon (Figure 37). This is within the most likely time of historical spawning (mid-March to June), based on basin-wide observations of spawning for the species (see Table 2). For all future scenarios (25%, 50%, 75% exceedance), TDDs necessary for spawning are not reached at Lees Ferry, occur only for the 25% exceedance hydrograph at the LCR, but are suitable in Havasu Creek and Diamond Creek.

The model predicted suitable spawning conditions (TDDs) for the Humpback Chub at Lees Ferry as late as December because of the delayed warming of dam releases. The Humpback Chub is typically a spring spawner that is presented with sub-optimal temperature in spring, and it is unlikely that the species would spawn in late summer and fall. Further downstream, at the LCR, suitable TDDs are reached in June through mid-August, which is within the time frame observed for the species spawning in other parts of the basin (see Table 2). From about Havasu Creek downstream, temperatures are suitable for spawning under all projected temperature regimes. This is confirmed with recent collections and observations of fish of all ages and evidence of mainstem spawning in western Grand Canyon (see sections 3.1.1, 3.1.3, and 4.5.6).

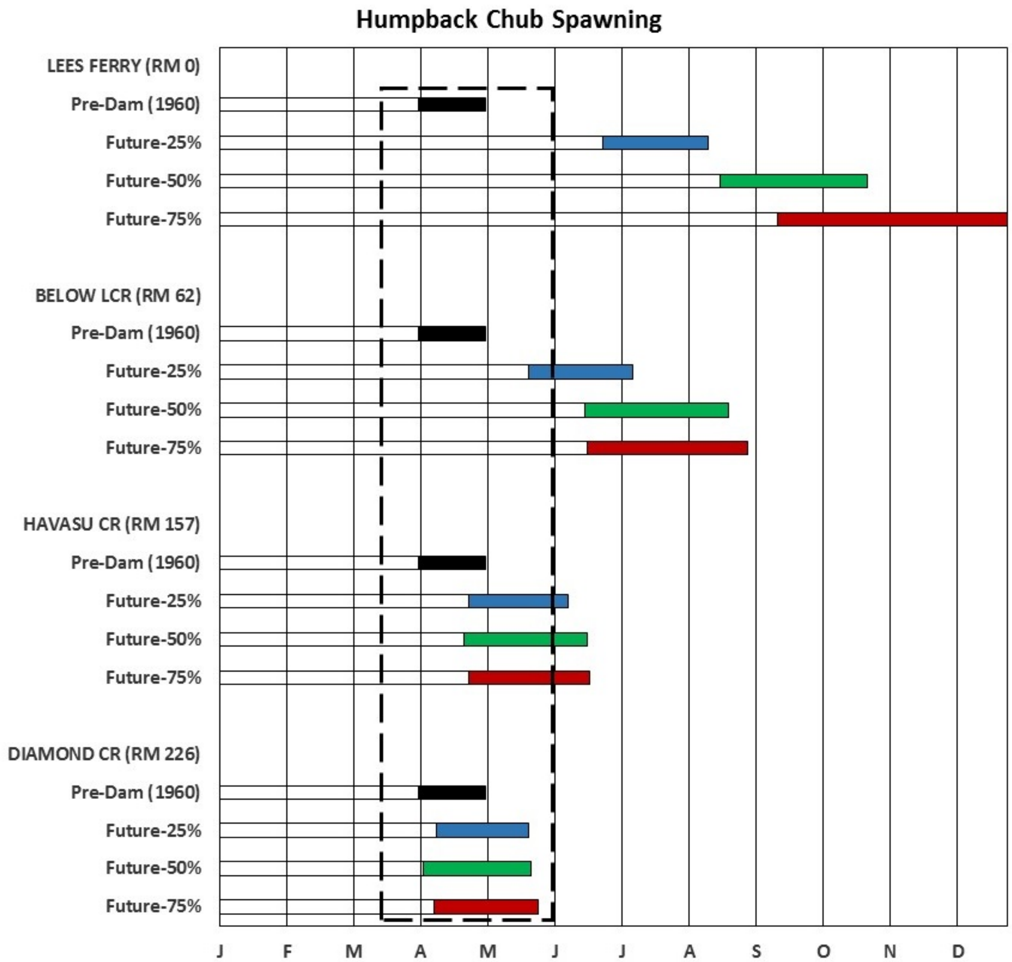


Figure 13. Projected timing of spawning for Humpback Chub during pre-dam (1960), representative years equal to 25%, 50%, and 75% exceedance of projected temperature. The length of each colored bar indicates the time when temperature is suitable for spawning; uncolored bars indicate that temperature is not suitable for spawning. Dashed boxes delineate most likely spawning time for the species.

A similar response is expected for three other native fish species in the Grand Canyon besides the Humpback Chub (Flannelmouth Sucker, Bluehead Sucker, and Razorback Sucker, Figures 38 and 39). If future condition is warm dam releases from lowered Lake Powell elevation (25% exceedance), conditions will continue to be unsuitable for spawning by any of the four native fishes at Lees Ferry, but will be suitable downstream of the LCR. For cooler releases (50% and 75% exceedance), TDDs for spawning will not be suitable for native species at Lees Ferry, marginally suitable at the LCR, and suitable in downstream locations. It is important to note that although temperature is important to these populations, other aspects of the river system are equally important, including food and the interactions with other species (Dzul et al. 2017).

The benefits of warm water can also extend to nonnative fish species that are predators and competitors of the Humpback Chub. Timing of spawning for six nonnative species (Brown

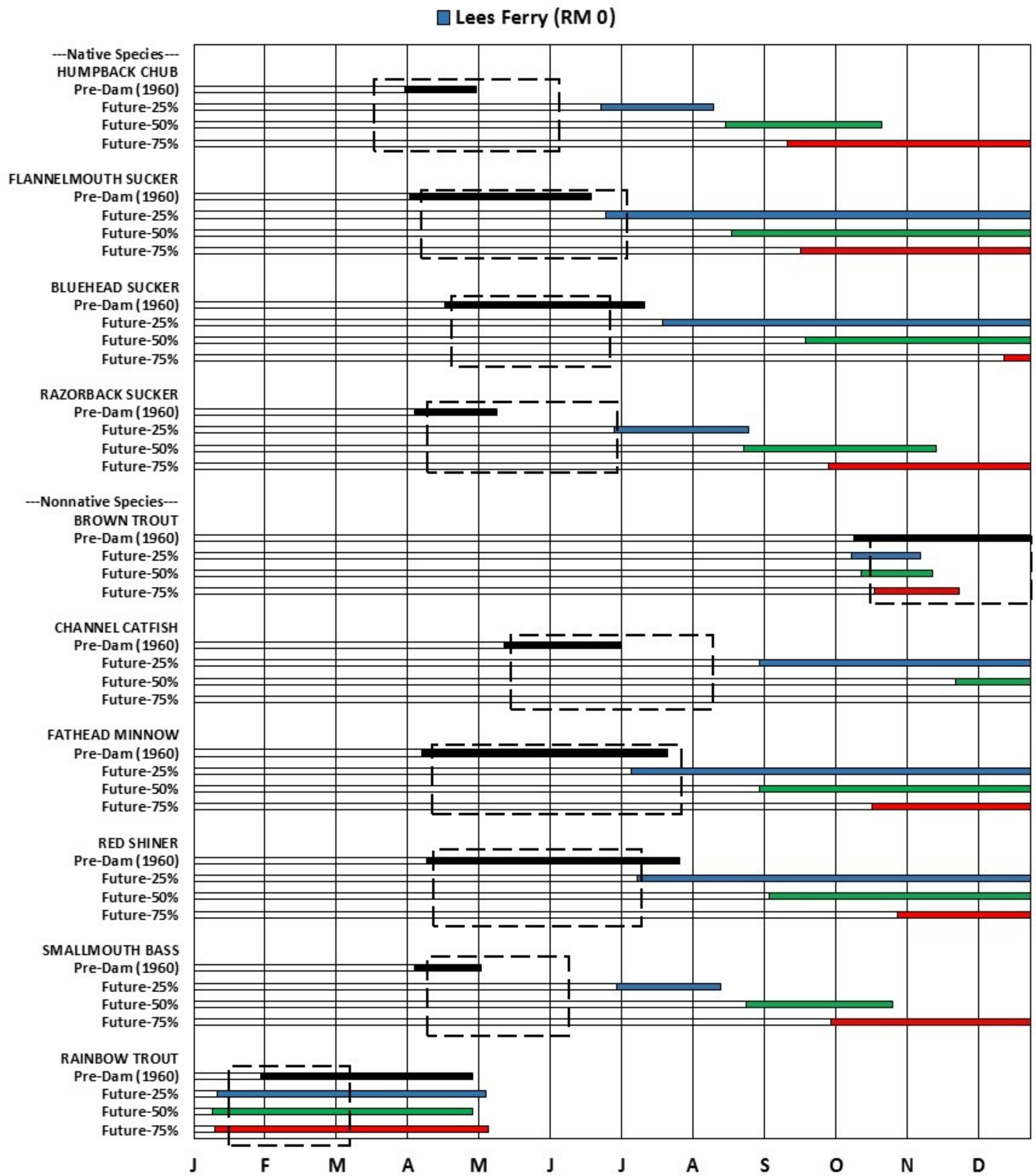
Trout, Channel Catfish, Fathead Minnow, Red Shiner, Smallmouth Bass, Rainbow Trout) at water temperatures for pre-dam (1960) and 25%, 50%, and 75% exceedance are also shown on Figure 38 and 39 for four locations downstream of Glen Canyon Dam. Suitable TDDs for spawning at warmest projected condition is reached at Lees Ferry only for the Rainbow Trout, but for all six warm-water species downstream of the LCR. The recent increase in Brown Trout in Lees Ferry, with evidence of reproduction, may be attributed to warmer fall releases combined with fall High Flow Experiments (HFEs; Brown Trout Workshop, September 21-22, 2017, Phoenix, AZ).

Projected temperature for Grand Canyon and modeled TDD suitability indicate that water temperature in Grand Canyon is likely to become increasingly suitable for spawning by the Humpback Chub—but also for key nonnative fish species, especially warm-water forms. This suitable temperature range is likely to occur downstream of the LCR starting in late May or early June, but advancing in time to early April at more downstream locations near Diamond Creek. The effect of future warming from low reservoir elevation will be spawning times in July for upstream reaches (LCR) and advancing to earlier times at downstream reaches (Diamond Creek) with longitudinal warming.

For the next 10–15 years, reservoir elevation and dam release temperature are not expected to change appreciably, but the long term is more uncertain. If the current pattern in reduced water availability continues and Lake Powell elevation drops to levels where the penstocks entrain epilimnetic water (e.g., 3,530–3,550 feet), warm water would flow into the Grand Canyon on an annual basis, though not with the same pattern as pre-dam condition. Instead, warm releases would mirror reservoir epilimnetic temperatures and produce 16–18°C as early as June and 20–23°C in mid-summer and early fall (Hart and Sherman 1996).

If the likely future includes epilimnetic dam releases, currently no mechanism exists to manage or mitigate this effect (e.g., temperature control device), and nonnative warm-water fishes could expand and present a substantial risk to Humpback Chub in the Grand Canyon. With Lake Powell elevation as a predictor of these conditions, it is imperative to develop detailed and effective nonnative fish management strategies to avert a large increase of predators and competitors that could lead to a decline in the Humpback Chub population.

Although these changes are expected to take place slowly over decades, with effects to fish populations that could become manifest over generations, a more dramatic effect is possible if threshold levels of temperature suitability are exceeded and a given fish species is suddenly and quickly able to successfully reproduce and recruit—such as the Smallmouth Bass in the Yampa River starting in the year 2000.


Lees Ferry (RM 0)
---Native Species---
HUMPBACK CHUB
Pre-Dam (1960)
Future-25%
Future-50%
Future-75%
FLANNELMOUTH SUCKER
Pre-Dam (1960)
Future-25%
Future-50%
Future-75%
BLUEHEAD SUCKER
Pre-Dam (1960)
Future-25%
Future-50%
Future-75%
RAZORBACK SUCKER
Pre-Dam (1960)
Future-25%
Future-50%
Future-75%
---Nonnative Species---
BROWN TROUT
Pre-Dam (1960)
Future-25%
Future-50%
Future-75%
CHANNEL CATFISH
Pre-Dam (1960)
Future-25%
Future-50%
Future-75%
FATHEAD MINNOW
Pre-Dam (1960)
Future-25%
Future-50%
Future-75%
RED SHINER
Pre-Dam (1960)
Future-25%
Future-50%
Future-75%
SMALLMOUTH BASS
Pre-Dam (1960)
Future-25%
Future-50%
Future-75%
RAINBOW TROUT
Pre-Dam (1960)
Future-25%
Future-50%
Future-75%
J F M A M J J A S O N D

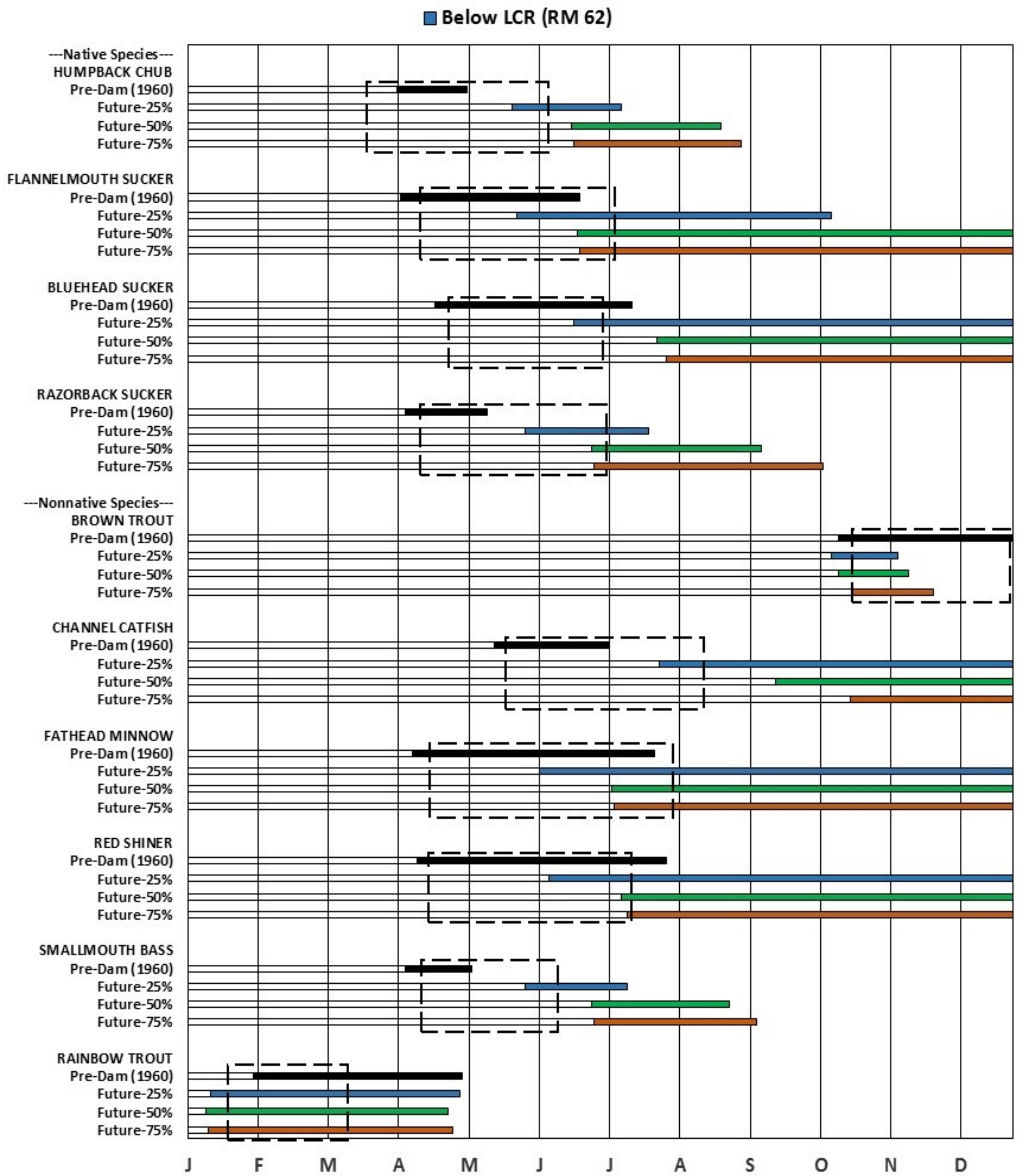
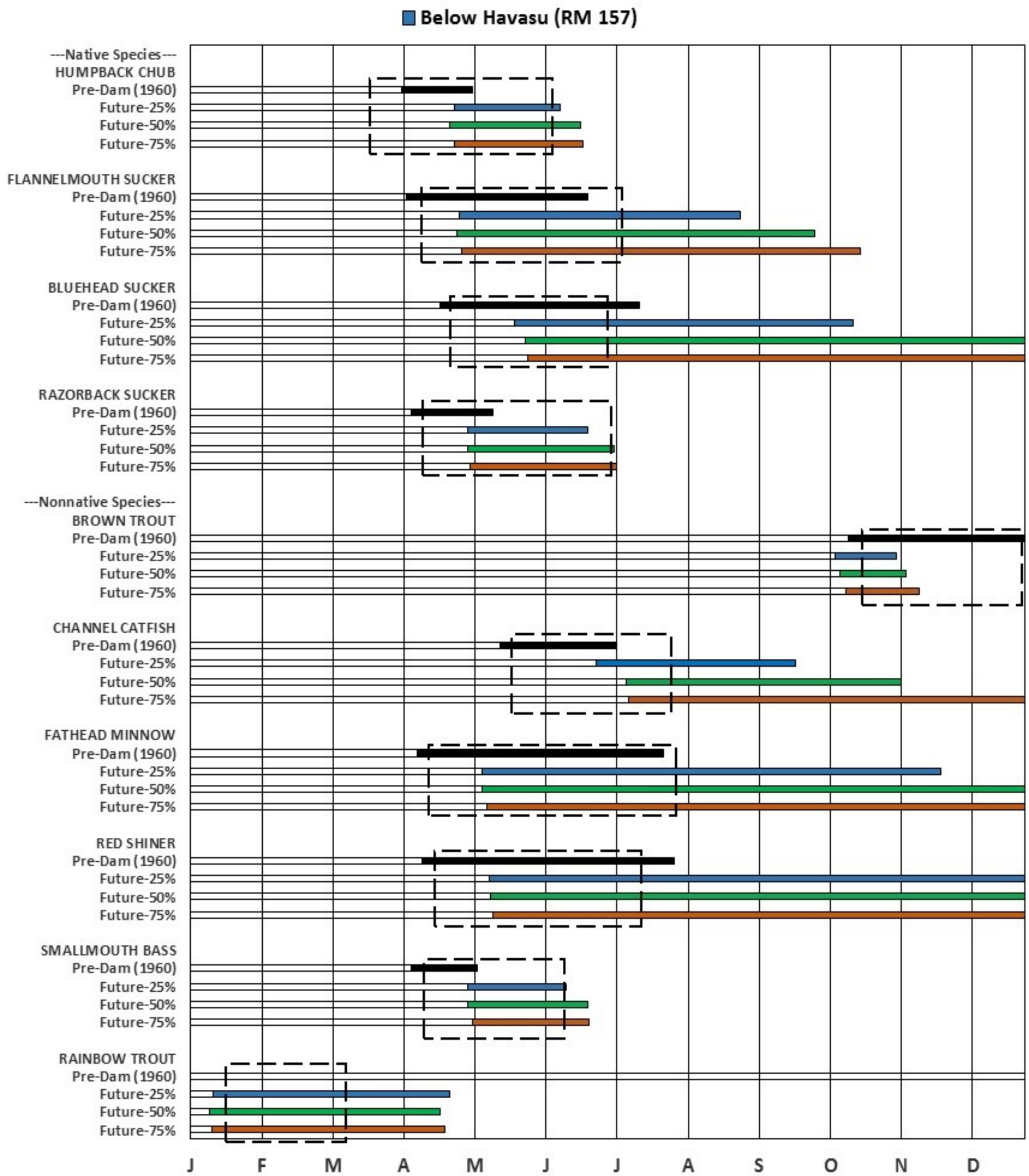


Figure 14. Timing of spawning at Lees Ferry and below the LCR for four native species (Humpback Chub, Flannelmouth Sucker, Bluehead Sucker, Razorback Sucker) and six nonnative fishes (Brown Trout, Channel Catfish, Fathead Minnow, Red Shiner, Smallmouth Bass, Rainbow Trout) at water temperatures for pre-dam (1960), and representative years equal to 25%, 50%, and 75% exceedance of projected temperature. The length of each colored bar indicates the time when temperature is suitable for spawning; uncolored bars indicate that temperature is not suitable for spawning. Dashed boxes delineate most likely spawning time by species.


Below Havasu (RM 157)
---Native Species---
HUMPBACK CHUB
Pre-Dam (1960)
Future-25%
Future-50%
Future-75%
FLANNELMOUTH SUCKER
Pre-Dam (1960)
Future-25%
Future-50%
Future-75%
BLUEHEAD SUCKER
Pre-Dam (1960)
Future-25%
Future-50%
Future-75%
RAZORBACK SUCKER
Pre-Dam (1960)
Future-25%
Future-50%
Future-75%
---Nonnative Species---
BROWN TROUT
Pre-Dam (1960)
Future-25%
Future-50%
Future-75%
CHANNEL CATFISH
Pre-Dam (1960)
Future-25%
Future-50%
Future-75%
FATHEAD MINNOW
Pre-Dam (1960)
Future-25%
Future-50%
Future-75%
RED SHINER
Pre-Dam (1960)
Future-25%
Future-50%
Future-75%
SMALLMOUTH BASS
Pre-Dam (1960)
Future-25%
Future-50%
Future-75%
RAINBOW TROUT
Pre-Dam (1960)
Future-25%
Future-50%
Future-75%
J F M A M J J A S O N D

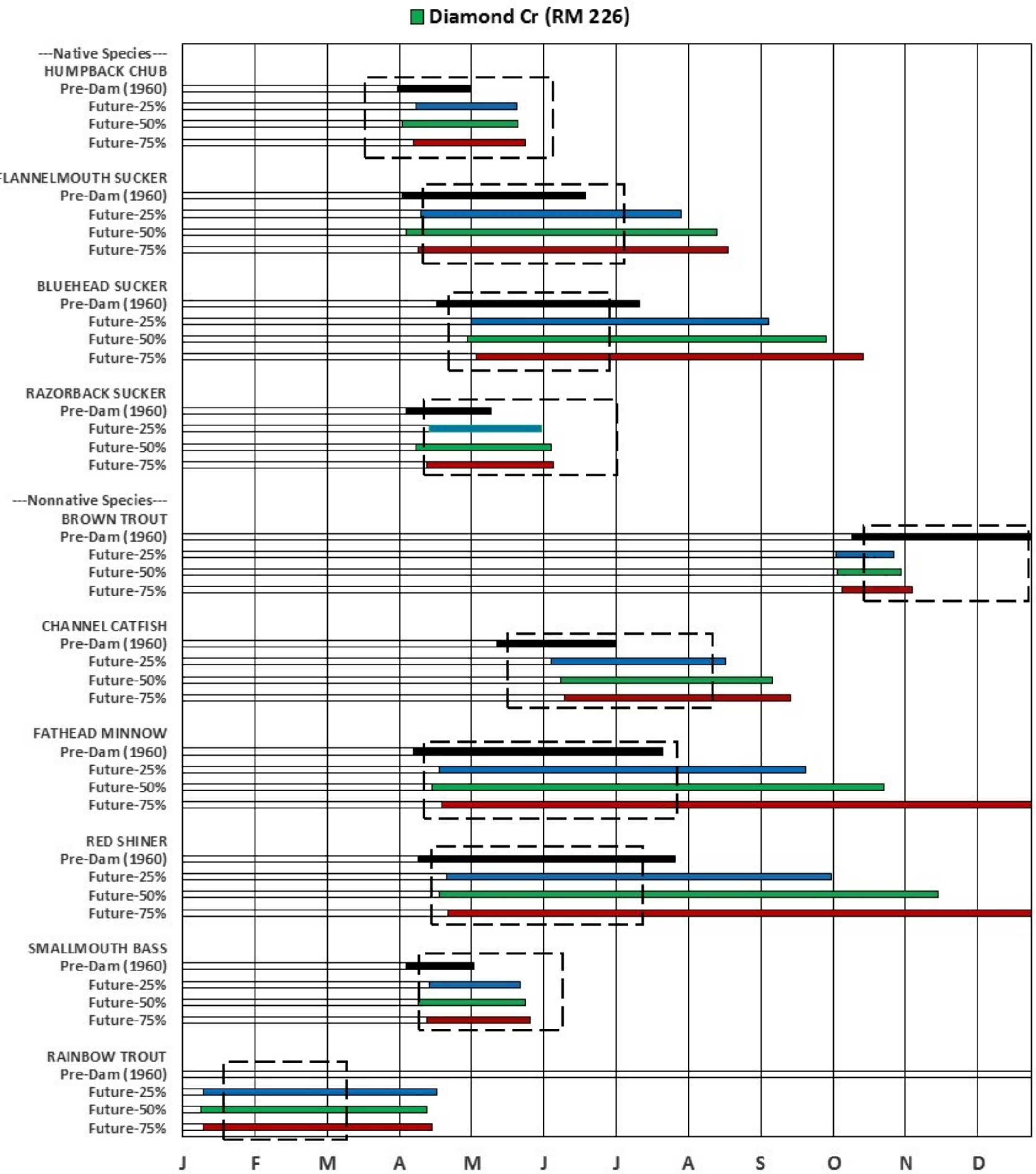


Figure 15. Timing of spawning below Havasu Creek and at Diamond Creek for four native species (Humpback Chub, Flannelmouth Sucker, Bluehead Sucker, Razorback Sucker) and six nonnative fishes (Brown Trout, Channel Catfish, Fathead Minnow, Red Shiner, Smallmouth Bass, Rainbow Trout) at water temperatures for pre-dam (1960) , and representative years equal to 25%, 50%, and 75% exceedance of projected temperature. The length of each colored bar indicates the time when temperature is suitable for spawning; uncolored bars indicate that temperature is not suitable for spawning. Dashed boxes delineate most likely spawning time by species.

APPENDIX C: Future Condition of Humpback Chub at 40-year timeframe

Chapters 5 and 6 evaluated the condition of the Humpback Chub 16 years into the future, a biologically meaningful timeframe based on the generation time for the species. To evaluate the risk to the species across longer timeframes, the U.S. Fish and Wildlife Service (USFWS) conducted additional analysis into the species condition up to 40 years into the future. This process provided consideration of the future condition of the species over additional generations, evaluated longer-term changes in resource condition, and incorporated the uncertainty of a longer-term future. Although this is a qualitative evaluation, it is strongly based on the Science Advisory Team's input concerning the current and future condition of Humpback Chub resource conditions, threat evaluations (primarily nonnative predators), and species population dynamics.

USFWS staff used the Science Advisory Subgroup's viability metrics at 0 years (current condition) and at 16 years for all three scenarios (future conditions) as the basis for projecting the future condition of Humpback Chub at 40 years. First, the viability metrics at 0 years and 16 years for all three scenarios were plotted. Existing tables in the SSA report (Table 7 for the current condition and Tables 19 and 20 for 16 years) supported these data points. Next, the data point for each scenario at 16 years was related back to the current condition (0 years) to create a 16-year trend line. Finally, the trend between the 0 and 16-year metric for each scenario was extrapolated out to 40 years (Figure 1). Extrapolations were linear for scenarios 2 and 3 and asymptotic for scenario 1. Scenario 1 was extrapolated with an asymptotic line because the Grand Canyon population would likely persist, but the overall species' redundancy and representation would be severely degraded by conditions in the upper basin.

In Figure 1, we also communicated uncertainty surrounding each future viability projection using a shaded area of the projection color. These bands of uncertainty are qualitative representations of the USFWS staff's judgment. That is, uncertainty bands are a communication tool, not based on quantitative information. The basis for increasing uncertainty after the 16 year biologically meaningful timeframe, as discussed in the SSA, is as follows:

- The population growth rate of several upper basin populations is uncertain;
    - Both the Black Rocks and Westwater Canyon populations declined in the early 2000s, but have apparently stabilized over the past decade. Confidence in the apparent stabilization is low to moderate, and more data points are needed; and
    - The Desolation and Gray canyons and Cataract Canyon populations persist, but available monitoring data are not sufficient to make claims of changes over time.
- Expansion of nonnative predatory species, especially Smallmouth Bass, could still occur in the upper basin. Future conditions (e.g. prolonged drought) could cause establishment or expansion of these or new nonnative species;
- The adequacy of the food base to support the Grand Canyon population is uncertain; and
- A warming trend in water released from Glen Canyon Dam presents a real risk of future nonnative species invasion in the lower basin.

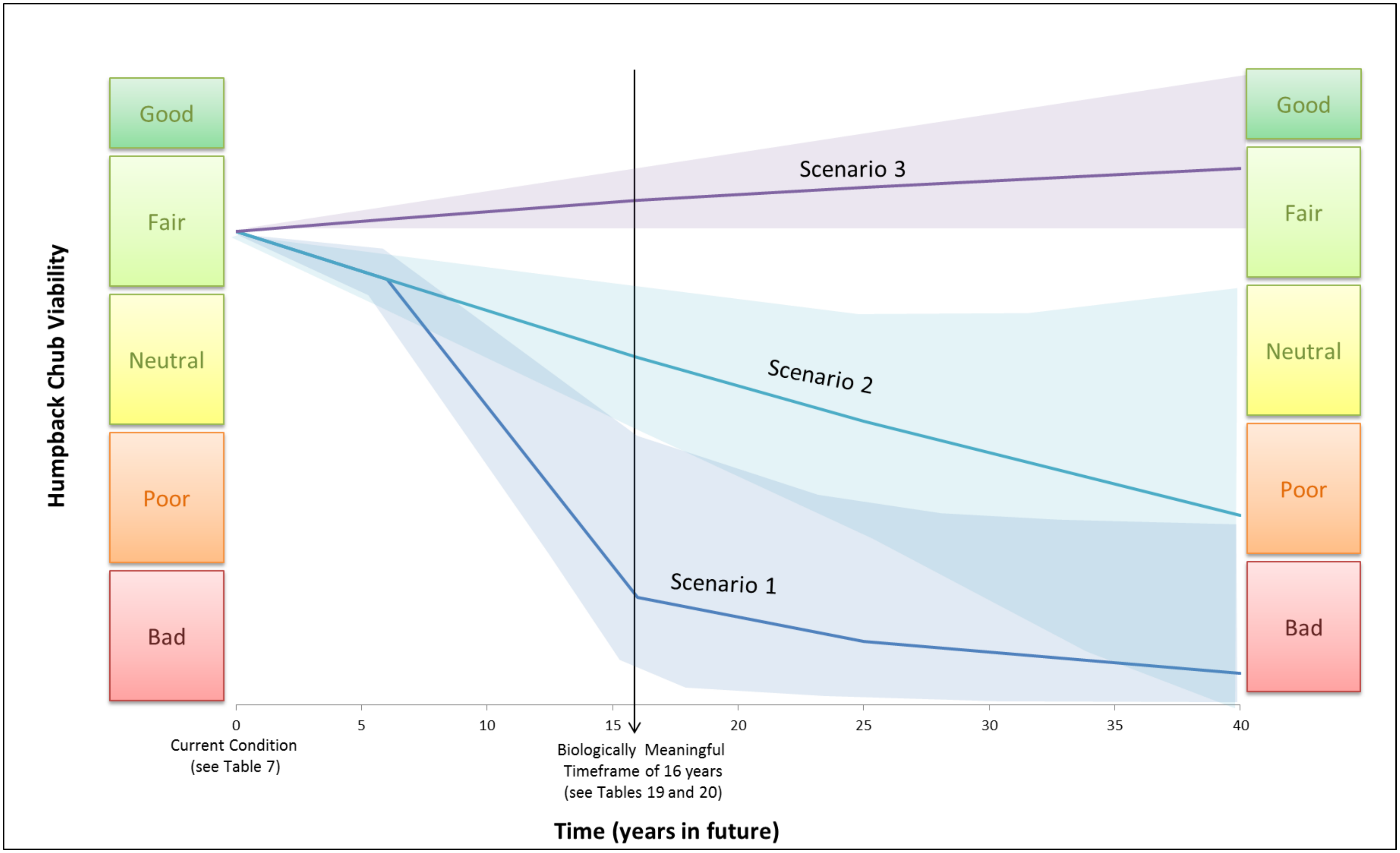


Figure 1. Humpback Chub viability projections forty years into the future. Data points at zero and 16 years are based on Tables 7, and 19 and 20 of the SSA report, respectively. Shaded area represents possible ranges of outcomes, communicating uncertainty of projections.

Summary of Scenarios Extrapolations to 40 years

Scenario 1, entitled "Environmental Stressors Increase and New or Discretionary Extralegal Actions are Eliminated", describes increasing threats and simultaneously diminishing management actions to only those required by law (such as under existing NEPA Records of Decisions). Importantly, this scenario includes a potentially significant downsizing of the collaborative partnership in the upper basin, the Upper Colorado River Endangered Fish Recovery Program (UCREFRP), when cooperative agreements expire in 2023[1], but recognizes the lower basin's Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP) EIS's continued implementation. Under scenario 1, conditions degrade severely within both 16 and 40 years, primarily because of the unresolved future of the UCREFRP. Degraded resource conditions under scenario 1 could result in declining abundance in all upper basin populations, the possible loss of one or more upper basin populations, and potential declines in the Grand Canyon population. We chose to display this scenario with an asymptotic curve because the Grand Canyon population would likely persist, but both redundancy and representation would be severely degraded.

Scenario 2, entitled "Legally Mandated Management Actions and Additional Adaptive Management Actions (beyond those legally mandated) Continue at Current levels, but are Not Fully Effective at Mitigating Current and Potential Future Threats". This scenario describes increasing threats and correspondingly increasing management actions, but those actions are not fully effective at reducing impacts from reduced water and nonnative fish. This scenario recognizes the commitment of stakeholders to improving Humpback Chub resource conditions, but also acknowledges that there is uncertainty about management effectiveness. Under scenario 2, degradation of resources takes place (albeit at a slower pace than under scenario 1), even as conservation actions continue, resulting in neutral conditions within 16 years, but poor conditions within 40 years. Although there is large uncertainty of resource conditions under scenario 2 at 40 years, extrapolation of the conditions demonstrates a continuing decline in resource conditions. Scenario 2 could result in gradual declines throughout the upper basin and possible loss of an additional population; declines in the Grand Canyon population are less likely. If these declines continue for a substantial period of time, species redundancy and representation would be impacted.

Scenario 3, entitled "Legally Mandated Management Actions and Adaptive Management Actions (beyond those legally mandated) Occur, and Are Effective" describes increasing threats and correspondingly increasing management actions, and those management actions are effective at improving or maintaining resource conditions. If collaborative partnerships remain in place and their conservation actions are effective, as described under scenario 3, resource conditions improve at 16 and 40-year timeframes. Scenario 3 recognizes the commitment of stakeholders to improving Humpback Chub resource conditions and assumes we have the necessary tools to

[1] Note the divergent path of Scenario 1 upon expiration of the UCREFRP in 2023.

arrest resource degradation. Scenario 3 could result in stabilization and possible improvement in the upper basin populations; stable or increasing Grand Canyon populations are also likely.

The potential extirpation of multiple populations could most likely occur in the upper basin under the short 16-year timeframe in scenario 1 and the longer 40-year timeframe under scenario 2. The current health (resiliency) and distribution (redundancy) of all four populations (redundancy), coupled with sustained and adequate threat management, leads to species viability in the long term under scenario 3. Based on the current trajectory of several of the upper basin populations, the uncertainty associated with certain resource conditions, and the unresolved future of the collaborative partnership in the upper basin (the UCREFRP), species conditions and viability could severely degrade within 16 to 40 years depending upon which scenario occurs.