# RAZORBACK SUCKER
# (*Xyrauchen texanus*)
# RECOVERY GOALS

**RAZORBACK SUCKER (*Xyrauchen texanus*)**

# RECOVERY GOALS
## Amendment and Supplement to the Razorback Sucker Recovery Plan

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

**Approved:** Ralph O. Morgenweck
**Regional Director, Region 6, U.S. Fish and Wildlife Service**

**Date:** 8/1/02

## DISCLAIMER PAGE

These recovery goals amend and supplement the 1998 Razorback Sucker Recovery Plan. Recovery plans delineate reasonable actions that are believed to be required to recover and/or protect listed species. The U.S. Fish and Wildlife Service publishes these plans, which may be prepared with the assistance of recovery teams, contractors, State agencies, and others. Attainment of the objectives and provision of any necessary funds are subject to priorities, budgetary, and other constraints affecting the parties involved. Recovery plans do not necessarily represent the views nor the official positions or approval of any individuals or agencies involved in the plan formulation, other than the U.S. Fish and Wildlife Service. Recovery plans represent the official position of the U.S. Fish and Wildlife Service **only** after they have been signed by the Regional Director or Director as **approved**. Approved recovery plans are subject to modification as dictated by new findings, changes in species status, and the completion of recovery tasks.

# CITATION FOR THESE RECOVERY GOALS

**These recovery goals should be cited as follows:**

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A total of 69 comment letters from 66 individuals representing State, Federal, and private interests was accepted and considered by the U.S. Fish and Wildlife Service (Service) pursuant to the public review of the September 7, 2001, draft recovery goals for the four endangered fishes of the Colorado River Basin through the *Federal Register* Notice of Availability (66 FR 47033) and Notice of Reopening (66 FR 58748). The Service thanks those individuals for submitting comment letters and appreciates the valuable input. The Service also appreciates the input received through meetings with basin States, recovery or conservation programs, water and power interests, environmental groups, American Indian tribes, and other stakeholders.

# EXECUTIVE SUMMARY

This document amends and supplements the Razorback Sucker Recovery Plan of 1998. The purpose of this document is to describe site-specific management actions/tasks; provide objective, measurable recovery criteria; and provide an estimate of time to achieve recovery of the endangered razorback sucker (*Xyrauchen texanus*), according to Section 4(f)(1) of the Endangered Species Act of 1973, as amended. Recovery or conservation programs that include the razorback sucker will direct research, management, and monitoring activities and determine costs associated with recovery.

**Current Species Status:** The razorback sucker is listed as endangered under the Endangered Species Act of 1973, as amended. The species is endemic to the Colorado River Basin of the southwestern United States. Adults attain a maximum size of about 1 m total length (TL) and 5–6 kg in weight. Remaining wild populations are in serious jeopardy. Razorback sucker are currently found in small numbers in the Green River, upper Colorado River, and San Juan River subbasins; lower Colorado River between Lake Havasu and Davis Dam; reservoirs of Lakes Mead and Mohave; in small tributaries of the Gila River subbasin (Verde River, Salt River, and Fossil Creek); and in local areas under intensive management such as Cibola High Levee Pond, Achii Hanyo Native Fish Facility, and Parker Strip.

**Habitat Requirements and Limiting Factors:** Historically, razorback sucker were widely distributed in warm-water reaches of larger rivers of the Colorado River Basin from Mexico to Wyoming. Habitats required by adults in rivers include deep runs, eddies, backwaters, and flooded off-channel environments in spring; runs and pools often in shallow water associated with submerged sandbars in summer; and low-velocity runs, pools, and eddies in winter. Spring migrations of adult razorback sucker were associated with spawning in historic accounts, and a variety of local and long-distance movements and habitat-use patterns have been documented. Spawning in rivers occurs over bars of cobble, gravel, and sand substrates during spring runoff at widely ranging flows and water temperatures (typically greater than 14$^{o}$C). Spawning also occurs in reservoirs over rocky shoals and shorelines. Young require nursery environments with quiet, warm, shallow water such as tributary mouths, backwaters, or inundated floodplain habitats in rivers, and coves or shorelines in reservoirs. Threats to the species include streamflow regulation, habitat modification, competition with and predation by nonnative fish species, and pesticides and pollutants.

**Recovery Objective:** Downlisting and Delisting.

**Recovery Criteria:** Objective, measurable criteria for recovery of razorback sucker in the Colorado River Basin are presented for each of two recovery units (i.e., the upper basin, including the Green River, upper Colorado River, and San Juan River subbasins; and the lower basin, including the mainstem and its tributaries from Glen Canyon Dam downstream to the southerly International Boundary with Mexico) because of different recovery or conservation programs and to address unique threats and site-specific management actions/tasks necessary to minimize or remove those threats. Recovery of the species is considered necessary in both the upper and lower basins because of the present status of populations and existing information on razorback sucker biology. Self-sustaining populations will need to be established through augmentation. Without viable wild populations, there are many uncertainties associated with recovery of razorback sucker. The razorback sucker was listed prior to the 1996 distinct population segment (DPS) policy, and the U.S. Fish and Wildlife Service (Service) may conduct an evaluation to designate DPSs in a future rule-making process. These recovery goals are based on the best available scientific information, and are structured to attain a balance between reasonably achievable criteria and ensuring the viability of the species beyond delisting. These recovery criteria will need to be reevaluated and revised after self-sustaining populations are established and there is improved understanding of razorback sucker biology.

Downlisting can occur if, over a 5-year period: (1) genetically and demographically viable, self-sustaining populations are maintained in the Green River subbasin and **EITHER** in the upper Colorado River subbasin or the San Juan River subbasin such that — (a) the trend in adult (age 4+; ≥400 mm TL) point estimates for each of the two populations does not decline significantly, and (b) mean estimated recruitment of age-3 (300–399 mm TL) naturally produced fish equals or exceeds mean annual adult mortality for each of the two populations, and (c) each point estimate for each of the two populations exceeds 5,800 adults (5,800 is the estimated minimum viable population [MVP] needed to ensure long-term genetic and demographic viability); and (2) a genetic refuge is maintained in Lake Mohave of the lower basin recovery unit; and (3) two genetically and demographically viable, self-sustaining populations are maintained in the lower basin recovery unit (e.g., mainstem and/or tributaries) such that — (a) the trend in adult point estimates for each population does not decline significantly, and (b) mean estimated recruitment of age-3 naturally produced fish equals or exceeds mean annual adult mortality for each population, and (c) each point estimate for each population exceeds 5,800 adults; and (4) when certain site-specific management tasks to minimize or remove threats have been identified, developed, and implemented.

Delisting can occur if, over a 3-year period beyond downlisting: (1) genetically and demographically viable, self-sustaining populations are maintained in the Green River subbasin and **EITHER** in the upper Colorado River subbasin or the San Juan River subbasin such that — (a) the trend in adult point estimates for each of the two populations does not decline significantly, and (b) mean estimated recruitment of age-3 naturally produced fish equals or exceeds mean annual adult mortality for each of the two populations, and (c) each point estimate for each of the two populations exceeds 5,800 adults; and (2) a genetic refuge is maintained in Lake Mohave; and (3) two genetically and demographically viable, self-sustaining populations are maintained in the lower basin recovery unit such that — (a) the trend in adult point estimates for each population does not decline significantly, and (b) mean estimated recruitment of age-3 naturally produced fish equals or exceeds mean annual adult mortality for each population, and (c) each point estimate for each population exceeds 5,800 adults; and (4) when certain site-specific management tasks to minimize or remove threats have been finalized and implemented, and necessary levels of protection are attained.

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

**Management Actions Needed:**

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

**Estimated Time to Achieve Recovery:** Extant populations of razorback sucker are small with little or no recruitment. Therefore, use of hatchery fish (progeny of cultured brood stock) will be necessary to establish new populations or augment existing populations. Time to achieve recovery of the razorback sucker cannot be accurately estimated until self-sustaining populations are established through augmentation and habitat enhancement. The rate at which populations become established will depend on survival of stocked fish in the wild, integration of stocked fish with wild stocks, reproductive success, and recruitment. Response of the species to ongoing management activities will need to be assessed through monitoring, and strategies for recovery and estimates of time to achieve recovery will be reevaluated periodically. Based on current information and associated uncertainties, it is estimated that self-sustaining populations of razorback sucker will become established over the next 15 years. During this time, population dynamics and responses to management actions will be evaluated.

For razorback sucker populations to be self-sustaining, adults must reproduce and recruitment of young fish into the adult population must occur at a rate to maintain the population at a minimum of 5,800 adults. When this occurs, the definition of a "self-sustaining" population is met, and the "clock" starts on the downlisting and delisting process.

Once self-sustaining populations have been established, reliable population estimates, based on a multiple mark-recapture model, are needed for all populations over a 5-year monitoring period for downlisting and over a 3-year monitoring period beyond downlisting in order to achieve delisting. The accuracy and precision of each point estimate will be assessed by the Service in cooperation with the respective recovery or conservation programs, and in consultation with investigators conducting the point estimates and with qualified statisticians and population ecologists. Self-sustaining populations and first reliable point estimates for all populations are expected by 2015. If those estimates are acceptable to the Service and all recovery criteria are met, downlisting could be proposed in 2020 and delisting could be proposed in 2023.

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# 1.0 INTRODUCTION

## 1.1 Background

The razorback sucker *(Xyrauchen texanus)* is a large catostomid fish endemic to the Colorado River Basin (Minckley et al. 1991). Adults attain a maximum size of about 1 m total length (TL) and 5–6 kg in weight (Minckley 1973). The razorback sucker is currently listed as "endangered" under the Endangered Species Act of 1973, as amended (ESA; 16 U.S.C. 1531 *et. seq.*), under a final rule published on October 23, 1991 (56 FR 54957). A recovery plan was approved on December 23, 1998 (U.S. Fish and Wildlife Service 1998). The final rule for determination of critical habitat was published on March 21, 1994 (59 FR 13374), and the final designation became effective on April 20, 1994.

The razorback sucker is a member of a unique assemblage of fishes native to the Colorado River Basin, consisting of 35 species with 74% level of endemism (Miller 1959). It is one of four mainstem, big-river fishes currently listed as endangered under the ESA; others are the humpback chub (*Gila cypha*), bonytail (*G. elegans*), and Colorado pikeminnow (*Ptychocheilus lucius*; formerly Colorado squawfish; Nelson et al. 1998). The native fish assemblage of the Colorado River is jeopardized by large mainstem dams, water diversions, degraded water quality, habitat modification, nonnative fish species, and degraded water quality (Miller 1961; Minckley and Deacon 1991).

## 1.2 Purpose and Scope

This document amends and supplements the Razorback Sucker Recovery Plan of 1998 (Recovery Plan; U.S. Fish and Wildlife Service 1998). The purpose and scope are to assimilate current information on the life history of the species and status of populations to develop recovery goals associated with the five listing factors that [as specified under Section 4(f)(1) of the ESA] identify site-specific management actions necessary to minimize or remove threats; establish objective, measurable recovery criteria; and provide estimates of the time and costs required to achieve recovery. In developing the recovery goals, the full body of available information pertinent to issues related to species life history and conservation was considered. However, it is not the intent of this document to provide a comprehensive treatise of information on razorback sucker; a synopsis of the life history that includes a description of habitat requirements is provided in Appendix A. Additional and more detailed information can be found in literature cited in this document and in reports and publications referenced in those citations.

These recovery goals were developed as an amendment and supplement to the Recovery Plan to focus on the requirements of Section 4(f)(1)(B) of the ESA, which requires that the Secretary of the Interior incorporate into each plan site-specific management actions; objective, measurable criteria; and estimates of the time and costs to carry out those measures needed to achieve the plan's goal and to achieve intermediate steps toward that goal. The Recovery Plan did not contain those key requirements of the ESA; therefore, these recovery goals take precedence over the Recovery Plan. Recovery or conservation programs that include the razorback sucker (see section 1.3) will direct research, management, and monitoring activities and determine costs associated with recovery. The recovery goals are not intended to include specifics on design of management strategies nor are they intended to prescribe ways that management strategies should be implemented. Those details (and associated costs) need to be developed by the respective recovery or conservation programs in their implementation plans.

An important aspect in development of these recovery goals was to attain a balance between reasonably achievable criteria and ensuring the viability and security of the species beyond delisting. Reasonably achievable criteria considered demographic and genetic requirements of self-sustainability. These recovery goals are intended to be used by the U.S. Fish and Wildlife Service (Service) in rule-making processes to downlist and/or delist the razorback sucker. The Service intends to review, and revise as needed, these recovery goals at least once every 5 years from the date they are made public through a Notice of Availability published in the *Federal Register*, or as necessary when sufficient new information warrants a change in the recovery criteria. Review of these recovery goals will be part of the review of listed species as required by Section 4(c)(2)(A) of the ESA, *"The Secretary shall ... conduct, at least once every five years, a review of all species..."*.

## 1.3 Recovery or Conservation Programs

All five major endangered-species recovery or conservation programs of the Colorado River Basin include the razorback sucker (Box 1). These are the Upper Colorado River Endangered Fish Recovery Program (UCRRP), the San Juan River Basin Recovery Implementation Program (SJRRIP), the Glen Canyon Dam Adaptive Management Program (GCDAMP), the Native Fish Work Group (NFWG), and the Lower Colorado River Multi-Species Conservation Program (MSCP). The UCRRP is a recovery program that was initiated under a Cooperative Agreement signed by the Secretary of the Interior on January 22, 1988, as a coordinated effort of State and Federal agencies, water users, energy distributors, and environmental groups to recover the four endangered fishes in the upper basin downstream to Glen Canyon Dam, excluding the San Juan River (U.S. Department of the Interior 1987; Wydoski and Hamill 1991; Evans 1993). It functions under the general principles of adaptive management (see section 5.1.2) and consists of seven program elements, including instream flow protection; habitat restoration; reduction of nonnative fish and sportfish impacts; propagation and genetics management; research, monitoring, and data management; information and education; and program management. The SJRRIP is a similar recovery program, established under a

**Box 1. Recovery or Conservation Programs**

1. Upper Colorado River Endangered Fish Recovery Program (UCRRP)
2. San Juan River Basin Recovery Implementation Program (SJRRIP)
3. Glen Canyon Dam Adaptive Management Program (GCDAMP)
4. Native Fish Work Group (NFWG)
5. Lower Colorado River Multi-Species Conservation Program (MSCP)

cooperative agreement signed in 1992, to conserve populations of Colorado pikeminnow and razorback sucker in the San Juan River Basin (U.S. Department of the Interior 1995a). As stated in the governing documents of the UCRRP and SJRRIP, the goal is to recover the endangered fishes while water development proceeds in compliance with State and Federal laws, including the ESA, State water law, interstate compacts, and Federal trust responsibilities to American Indian tribes. Funding for the UCRRP and SJRRIP will continue through 2011 under legislation passed in October 2000 (P.L. 106-392); Congress will review the UCRRP and SJRRIP to determine if funding should be authorized beyond 2011.

The GCDAMP is a conservation program that was established by the Secretary of the Interior under the Federal Advisory Committee Act to provide oversight on the operation of Glen Canyon Dam to protect and/or enhance development of the Colorado River ecosystem through Grand Canyon (i.e., mainstem Colorado River and its tributaries from Glen Canyon Dam downstream to Lake Mead National Recreation Area). The GCDAMP consists of a diverse group of stakeholders, including State and Federal agencies, water users, energy distributors, environmental groups, recreational interests, and American Indian tribes, that direct coordinated scientific studies by the Grand Canyon Monitoring and Research Center (GCMRC) of the U.S. Geological Survey. The GCDAMP addresses the elements of the Environmental Impact Statement on the operation of Glen Canyon Dam (U.S. Department of the Interior 1995b), as well as the reasonable and prudent alternatives contained in a jeopardy biological opinion for the humpback chub and razorback sucker in Grand Canyon. This adaptive-management program takes findings of the GCMRC as information for dam reoperations and conservation of the endangered fishes.

The NFWG is a conservation program coordinating efforts of State and Federal agency biologists, as well as university staffs and volunteers, to conserve and protect the genetic pool of razorback sucker and bonytail primarily in Lake Mohave (Burke and Mueller 1993).

The MSCP is a conservation program under development that was initiated in response to the designation of critical habitat for the four endangered “big river” fishes in 1994, and the listing of the southwestern willow flycatcher (*Empidonax traillii extimus*) as endangered in 1995 (SAIC/Jones & Stokes 2002). In response, representatives from the U.S. Departments of the Interior and Energy; several American Indian tribes; water, power, and wildlife resource management agencies from the three lower basin States; and a significant number of agricultural, municipal, and industrial providers of Colorado River water and power resources have formed a regional partnership that is developing a multi-species conservation program aimed at protecting sensitive, threatened, and endangered species of fish, wildlife, and their habitat. The partnership has formed a 27-member steering committee, which has been designated by the Service as an Ecosystem Conservation and Recovery Implementation Team under the ESA. The MSCP planning area comprises the historic floodplain of the Colorado River from Lake Mead to the southerly International Boundary with Mexico and areas to elevations up to and including the full pool elevations of Lakes Mead, Mohave, and Havasu (SAIC/Jones & Stokes 2002). The razorback sucker is one of 56 species proposed for coverage by the MSCP, and it is one of the six focus species.

# 2.0 THE RECOVERY PROCESS

## 2.1 Definition of Recovery

Understanding the Service's strategy for recovery of the razorback sucker, as provided in the ESA and implementing regulations, first requires an understanding of the meaning of "recover" and "conserve". The ESA does not specifically define recover, and the term "recovery" is used with respect to recovery plans *"...for the conservation and survival..."* of listed species. An endangered species, as defined in Section 3(6) of the ESA, means *"any species which is in danger of extinction throughout all or a significant portion of its range."* A threatened species is defined in Section 3(19) of 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."* According to Service policy (U.S. Fish and Wildlife Service 1990), *"Recovery is the process by which the decline of an endangered or threatened species is arrested or reversed, and threats to its survival are neutralized, so that its long-term survival in nature can be ensured. The goal of this process is the maintenance of secure, self-sustaining wild populations of species with the minimum necessary investment of resources."* The ESA's implementing regulations (50 CFR § 402.02) further define recovery as *"...improvement in the status of listed species to the point at which listing is no longer appropriate under the criteria set out in section 4(a)(1) of the Act."* The policy and regulations use the word recovery in a narrow ESA sense, giving it meaning that is different from returning a species to its normal position or condition.

The definition provided for recovery in the implementing regulations and the definition provided for conserve in the ESA have essentially the same meaning. Section 3(3) of the ESA states: *"The terms "conserve," "conserving," and "conservation" mean to use and the use of all methods and procedures which are necessary to bring any endangered species or threatened species to the point at which the measures provided pursuant to this Act are no longer necessary."* Hence, recovery and conserve both mean to bring a species to the point at which it no longer needs the protection of the ESA, because the species is no longer in danger of extinction throughout all or a significant portion of its range. This definition of recovery falls far short of requiring that a species must be restored to its historic range and abundance before it can be considered recovered or delisted. It also falls short of requiring the restoration of a species to all the remaining suitable habitat, unless this is necessary to sufficiently reduce the species' susceptibility to threats to a level at which the species is no longer threatened or endangered.

The phrase "throughout all or a significant portion of its range" is used in both definitions of endangered and threatened. Neither "significant" nor "range" are defined in the ESA or implementing regulations. Hence, the ESA provides the Service with latitude to use its discretion, based on the best scientific information available, to develop recovery goals and implement recovery plans designed to conserve and recover species. The ESA clearly does not use the term significant in a statistical sense. Significance cannot be reliably and safely applied in any strictly quantitative framework, because of the great variety of organisms, habitats, and threats that must be evaluated for protection under the ESA.

Given that the ESA is intended to avoid species extinction, the Service avoids the pitfalls of a purely quantitative approach by instead viewing significant in the context of a species' long-term survival needs. The term becomes logical, meaningful, and useful if applied in this context. A significant portion of the range is that area that is important or necessary for maintaining a viable, self-sustaining, and evolving population or populations, in order for a taxon to persist into the foreseeable future. That "significant portion" may constitute a large portion of the historic range of a species or a relatively small portion of the historic range. Other parts of a species' range (regardless of whether it is historical, current, or potential range) may not be significant to its long-term survival, regardless of its geographic extent. Therefore, a species extirpated from such areas does not necessarily mean it is threatened or endangered, regardless of the geographic extent of those areas.

Implicit in the ESA definitions of threatened and endangered and in the principles of conservation biology is the need to consider genetics, demographics, population redundancy, and threats (as identified by the listing factors). The ESA is mandated to recover species to the point that they are "not likely" to be in danger of extinction for the foreseeable future throughout all or a significant portion of their range. The Service believes that the "not likely" standard is exceeded by the requirement of the recovery goals to maintain multiple widespread populations that are independently viable, because it is unlikely that future singular threats will endanger widely separated multiple populations. Viable populations have sufficient numbers of individuals to counter the effects of deleterious gene mutations as a result of inbreeding, and to counter the effects of deaths exceeding births and recruitment failure for periods of time. Thus, the conservation biology principle of redundancy is satisfied by the required multiple genetically and demographically viable, self-sustaining populations (section 3.1.3). Furthermore, the principle of resiliency is satisfied with sufficiently large populations to persist through normal population variations, as well as through unexpected catastrophic events (section 3.1.4).

The principles of recovery and conservation as defined in the ESA, implementing regulations, and Service policy demonstrate the strong relationship between the delisting criteria used for recovery and the five listing factors in Section 4(a)(1) of the ESA. These five listing factors must be addressed in any reclassification of a species [ESA Section 4(c)(2)(B); section 4.0 of this document], and are:

"*(A) The present or threatened destruction, modification, or curtailment of its habitat or range;*
*(B) overutilization for commercial, recreational, scientific, or educational purposes;*
*(C) disease or predation;*
*(D) the inadequacy of existing regulatory mechanisms; and*
*(E) other natural or manmade factors affecting its continued existence.*"

Recovery is based on reduction or removal of threats and improvement of the status of a species during the period in which it is listed, and not just from the time a listed species is proposed for reclassification. Environmental conditions and the structure of populations change over time, and threats recognized at listing or in subsequent recovery plans may no longer be directly applicable when reclassification is considered. Management actions and tasks conducted by recovery or conservation programs for listed species are expected to minimize or remove threats and improve the species' status.

When delisting a species, the Service must determine that the five listing factors no longer apply, e.g., the habitat is no longer threatened with destruction or modification, the current abundance and range is adequate, and the habitat needed to sustain recovered populations is present. Therefore, the recovery goals (section 5.0) include management actions and tasks, as well as downlisting and delisting criteria, presented by "recovery factor". These recovery factors were derived from the five listing factors and state the conditions under which threats are minimized or removed.

Recovery is achieved when management actions and associated tasks have been implemented and/or completed to allow genetically and demographically viable, self-sustaining populations to thrive under minimal ongoing management and investment of resources. Achievement of recovery does not mandate returning a species to all or a significant portion of its historic range, nor does it mandate establishing populations in all possible habitats, or everywhere the species can be established or reestablished. Removing a species from protection of the ESA remands the primary management responsibility of that species to the States, who may choose to further expand its range and populations. The standard of establishing and protecting viable, self-sustaining populations is applied to the recovery of razorback sucker, and was used in developing recovery goals for the other three endangered fishes of the Colorado River Basin (U.S. Fish and Wildlife Service 2002a, 2002b, 2002c). This approach is consistent with recovery of other vertebrate species, such as the bald eagle (*Haliaeetus leucocephalus*; 64 FR 36453), peregrine falcon (*Falco peregrinus*; 64 FR 46541), desert tortoise (*Gopherus agassizii*; Berry 1999), Pacific salmon (*Oncorhynchus spp.*; Allendorf et al. 1997), and southern sea otter (*Enhydra lutris nereis*; Ralls et al. 1996).

## 2.2 Recovery Units

Recovery of razorback sucker in the Colorado River Basin is considered necessary in both the upper and lower basins because of the present status of populations and existing information on razorback sucker biology. For the purpose of these recovery goals, the upper and lower basins are divided at Glen Canyon Dam, Arizona. Separate objective, measurable recovery criteria were developed for each of two recovery units (i.e., the upper basin, including the Green River, upper Colorado River, and San Juan River subbasins; and the lower basin, including the mainstem and its tributaries from Glen Canyon Dam downstream to the southerly International Boundary with Mexico) to address unique threats and site-specific management actions necessary to minimize or remove those threats. The recovery units encompass five management areas under different and separate recovery or conservation programs (i.e., UCRRP, SJRRIP, GCDAMP, NFWG, and MSCP; see section 1.3 for description of geographic coverage by each of the programs). Designation of the recovery units is consistent with goals established by these programs. For example, the governing document for the UCRRP (U.S. Department of the Interior 1987) states: *"Since the recovery plans* [for the Colorado pikeminnow, humpback chub, and bonytail; razorback sucker was not federally listed in 1987, but was included in the UCRRP] *refer to* *species recovery in both the upper and lower basins, these goals* [recovery/management goals in the original recovery plans] *also apply to both basins, until revised for the upper basin, through implementation of this recovery program. However, the goal of this program for the three endangered species is recovery and delisting in the upper basin. In general, this would be accomplished when the habitat necessary to maintain self-sustaining populations has been determined and provisions are in place to maintain and protect that habitat and these species. The Implementation Committee will be expected to revise these goals for the upper basin as the program develops. Attainment of these goals will result in recovery and delisting of the listed species in the upper basin."* Parties to the UCRRP agreed that the four endangered species could be downlisted and delisted separately in the upper basin. However, the document also states: *"... this program can not, and does not in anyway, diminish or detract from or add to the Secretary's ultimate responsibility for administering the Endangered Species Act."*

The razorback sucker was listed prior to the 1996 distinct population segment (DPS) policy, and the Service may conduct an evaluation to designate DPSs in a future rule-making process. In the Policy Regarding the Recognition of Distinct Vertebrate Population (61 FR 4721–4725), the U.S. Fish and Wildlife Service and the National Marine Fisheries Service clarified their interpretation of the phrase *"distinct population segment of any species of vertebrate fish or wildlife"* for the purposes of listing, delisting, and reclassifying species under the ESA. Designation of DPSs is a separate listing process that is different from recovery plans/goals, and is accomplished by a rule- making process. A DPS is a segment of the population and includes a part of the range of a species or subspecies. Like all listings, the DPS is described geographically, but it is important to retain the purpose of the ESA *"...to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved..."*. The elements considered for designation of DPSs are: *"1) Discreteness of the population segment in relation to the remainder of the species to which it belongs; 2) The significance of the population segment to the species to which it belongs; and 3) The population segment's conservation status in relation to the Act's standards for listing (i.e., is the population segment, when treated as if it were a species, endangered or threatened?)."*

Species listed prior to the DPS policy may be reconsidered for DPS designation at the time of reclassification or at the 5-year status review. The DPS policy states: *"Any DPS of a vertebrate taxon that was listed prior to implementation of this policy will be reevaluated on a case-by-case basis as recommendations are made to change the listing status for that distinct population segment. The appropriate application of the policy will also be considered in the 5-year reviews of the status of listed species required by section 4(c)(2) of the Act."* Section 4(c)(2)(A) of the ESA requires a review of listed species *"at least once every five years"*. If DPSs are designated, these recovery criteria will need to be reevaluated.

## 2.3 Development of Recovery Goals

Development of recovery goals for the razorback sucker followed a specific process. First, current data on the life history of the species and on existing populations were assimilated (Appendix A; section 3.0). Second, the assimilated data were used to evaluate population viability and self-sustainability (section 3.0). Third, past and existing threats were identified according to the five listing factors (section 4.0). Finally, site-specific management actions were identified to minimize or remove threats, and objective, measurable recovery criteria were developed based on the five factors (section 5.0). The process of developing the recovery goals was interactive and iterative, and the recovery goals are the product of considerable input from stakeholders and scientists from throughout the Colorado River Basin and from rigorous peer review. Input from biologists and managers throughout the basin was received through meetings with the Colorado River Fishes Recovery Team; Biology, Management, and Implementation committees of the UCRRP; Biology and Coordinating committees of the SJRRIP; Native Fish, Technical, and Adaptive Management work groups of the GCDAMP; Colorado River Fish and Wildlife Council; American Indian tribes; State game and fish agencies; water and power interests; and appropriate Federal agencies. Input was also received through independent reviews of previous drafts (see acknowledgments). Development of these recovery goals considered the approach taken by Lentsch et al. (1998) to develop interim management objectives, and paralleled similar efforts by the Colorado Division of Wildlife and benefitted from exchange of information with the principal author (Nesler 2000).

The process of downlisting and delisting described in this document is consistent with provisions specified under Section 4(b), Basis For Determinations, and Section 4(f)(1), Recovery Plans, of the ESA. Under Section 4(b), the Secretary of the Interior shall determine if a species is endangered or threatened *"...solely on the basis of the best scientific and commercial data available..."*. Specifically, under Section 4(f)(1)(B), each recovery plan must incorporate (i) *"a description of such site-specific management actions as may be necessary to achieve the plan's goal for conservation and survival of the species"*; (ii) *"objective, measurable criteria which, when met, would result in a determination, in accordance with the provisions of this section, that the species be removed from the list"*; and (iii) *"estimates of the time required and cost to carry out those measures needed to achieve the plan's goal and to achieve intermediate steps toward that goal."* Objective, measurable recovery criteria identify downlisting and delisting requirements for each management action, and define viable, self-sustaining populations consisting of target numbers of adults and subadults for wild populations. Under Section 4(c)(2)(B) of the ESA, each determination of reclassification of a species shall be made in accordance with provisions of Sections 4(a) and 4(b).

# 3.0 POPULATION VIABILITY AND SELF-SUSTAINABILITY

Population viability and self-sustainability are the cornerstones to defining a recovered species. Factors that determine population viability and self-sustainability are demographics (size and age structure of populations), population redundancy (number and distribution of populations), habitat carrying capacity (resource limitations), and genetic considerations (inbreeding and genetic viability). The primary objective of the Recovery Plan is: *"The short-term goal for the recovery of the razorback sucker is to prevent extinction." "The long-term goal is to recover the fish to the point that it may be down listed and then delisted."* This section discusses the development of genetic and demographic viability standards for achieving self-sustaining populations, in order to address the need of the Recovery Plan for *"...a razorback sucker* *population size of...adult fish...with adequate numbers of naturally-recruited immature fishes to sustain this target adult population size...”*. Furthermore, these *“...populations shall reach a sufficient size to maintain genetic diversity and to be relatively secure from potential threats...”*. Guidelines for population viability and self-sustainability are stated in Box 2 (Franklin 1980; Soulé 1980; Shaffer 1987; Allen et al. 1992).

**Box 2. Guidelines for Population Viability and Self-Sustainability**

- A viable, self-sustaining population has negligible probability of extinction over a 100- to 200-year period.
- A population should be sufficiently large to survive historically observed environmental variation.
- A population should be sufficiently large to maintain long-term genetic diversity and viability.
- Multiple demographically viable (redundant) populations greatly reduce the probability of extinction if the populations are independent in their susceptibility to catastrophic events.
- A viable, self-sustaining population must have positive recruitment potential sufficient to replace adult mortality near carrying capacity, and on average, exceed adult mortality when the population is below carrying capacity.
- Carrying capacity is not expected to be the same for different populations, because physical habitat, water quality, and biological components are likely to vary.

## 3.1 Demographic Viability

### *3.1.1 Demographic characteristics, environmental uncertainty, and catastrophic events*

Demographic or population viability refers to the persistence of a species over time, as affected by uncertainties in population dynamics. A viable, self-sustaining population has negligible probability of extinction over a 100- to 200-year time frame (Franklin 1980; Soulé 1980). Population viability can be affected by demographic characteristics, environmental uncertainty, and catastrophic events (Shaffer 1987; Allen et al. 1992). Demographic characteristics relate to random changes in birth and death rates, primarily reflecting differences at the population level. Persistence time for a population faced only with demographic variability increases geometrically as the population increases, and only populations with individuals that number in the “10s to 100s” are vulnerable to extinction due simply to demographic variability (Shaffer 1987). Hence, demographic viability is generally considered to be an issue only with severely depleted populations (Goodman 1987; Allen et al. 1992), such as the razorback sucker. Although razorback sucker in Lake Mohave number in the thousands, low reproductive success, low survival of young, and little or no recruitment have contributed to high demographic uncertainty. Wild razorback sucker populations in many locations of the Colorado River Basin have become aged, senile, and perished from inadequate recruitment.

Population persistence decreases linearly with environmental uncertainty (Shaffer 1987), which is also a major factor in the decline of the razorback sucker. Environmental uncertainty results from changes in environmental factors such as variability in food supply; weather; population dynamics of predators, competitors and parasites; and in the case of riverine fishes, variability in seasonal flow characteristics. Many of these environmental factors may be highly correlated to population demographics, such as reproductive success, survival, and recruitment. Population sizes necessary for persistence under environmental variability reflect the resulting variability in birth and death rates (Allen et al. 1992). Specifically linking environmental variability to birth and death rates is difficult (Ewens et al. 1987), and use of a demographic model for razorback sucker is limited because of the lack of reliable empirical data on these life-history parameters. Population viability analyses (PVA; Gilpin 1993; Soulé 1987; Shaffer 1987) were considered but not employed because of a lack of conclusive data on state and rate variables for the species.

As an alternative to demographic models, the concept of carrying capacity can be used to approximate population sizes and potential. Populations can be viewed as having some potential with respect to resource limitations or theoretical carrying capacity. The variance (V) in potential growth rate (r), without limitations of carrying capacity, has to be sizably greater than r ($V > 2r$) before the population is susceptible to extinction, otherwise the population tends toward the carrying capacity (Roughgarden 1979). This is difficult to ascertain for the razorback sucker because historic population sizes are not well known and existing populations are greatly depleted.

Catastrophic events could also dramatically impact razorback sucker populations. Catastrophic events are rare incidents that may cause sizable mortality in one or more age groups. A catastrophe is an event that would, with a single act, eliminate one or more ages of razorback sucker in a reach of river. This may include such factors as dramatic and extensive alteration of riverine habitat, invasion of nonnative fishes as highly successful predators or competitors, or spills of toxic substances. Abundance and distribution of razorback sucker were greatly reduced by the 1930's as a result of land-use practices, degraded water quality, and nonnative fishes (Dill 1944; Miller 1961). Further reduction and extirpation from many regions of the Colorado River Basin followed construction of mainstem dams, which affected specific life-history events by impeding passage to spawning, feeding, and nursery areas; eliminating availability of floodplain nursery areas; causing reproductive failure from cold-water releases; and reducing survival through the introduction of successful nonnative predators and competitors. A rotenone treatment in Flaming Gorge Canyon in the early 1960's killed unknown numbers of razorback sucker (Holden 1991) but did not extirpate the species from the Green River, nor did an oil spill on the Yampa River in 1987. In order for the razorback sucker to become extinct, a catastrophe would have to be of the magnitude where the entire ecosystem is fragmented and altered.

Although razorback sucker are long-lived fishes (40+ years), persistent recruitment failure has depleted and extirpated numerous populations. In the case of lower basin reservoirs (i.e., Mead, Mohave, Havasu), the characteristic chronology of extirpation is 40–50 years following dam construction (Minckley et al. 1991); i.e., the fish that were produced prior to habitat inundation and fragmentation reach maximum longevity with little or no recruitment to replace adult mortality. This occurred as a result of inundated riverine habitat and poor survival of reproduced young because of predation by nonnative fishes.

### *3.1.2 Existing populations of razorback sucker*

Razorback sucker are currently found in the Green River, upper Colorado River, and San Juan River subbasins; lower Colorado River between Lake Havasu and Davis Dam; reservoirs of Lakes Mead and Mohave; and in small tributaries of the Gila River subbasin (Verde River, Salt River, and Fossil Creek; Table 1; Figure 1; Appendix A). The fish in most populations are aged and senile adults with little or no recruitment, except for the middle Green River and Lake Mead, where small numbers of juveniles and young adults indicate low recruitment levels (Modde et al. 1996; Holden et al. 1999a, 1999b). Intensive management in some locations has helped to offset the decline of the razorback sucker, such as the capture and protective rearing of larvae in Lake Mohave for release at larger sizes, and raising of young in predator-free environments in Cibola High Levee Pond; a 2-ha pond containing approximately 3,000 razorback sucker with reproduction and recruitment (Marsh 2000).

The largest population of razorback sucker in the Upper Colorado River Basin exists in low-gradient, flat-water reaches of the middle Green River between the Duchesne River and Yampa River (Tyus 1987; Bestgen 1990; Muth et al. 2000). Tag-recapture and telemetry data indicate that razorback sucker in the middle Green River constitute a single reproducing population (Modde and Irving 1998). Known spawning sites are located in the lower Yampa River and in the Green River near Escalante Ranch between river km 492 and 501 (distance upstream from Colorado River confluence), but other, less-used sites are probable (Tyus and Karp 1990; Modde and Wick 1997; Modde and Irving 1998). Lanigan and Tyus (1989) estimated a middle Green River population of 948 adults (95% confidence interval: 758–1,138). Eight years later, the population was estimated at 524 adults (95% confidence interval: 351–696), and characterized as being stable or declining slowly with some evidence of recruitment (Modde et al. 1996). The suspected recruitment was attributed to unusually high spring flows during 1983–1986 that inundated portions of the floodplain used as nurseries by the young.

In recent years, only a few individual razorback sucker have been captured in the lower Green River; small numbers of larvae and juveniles indicate probable spawning in the vicinity of the San Rafael River confluence (Gutermuth et al. 1994; Chart et al. 1999; Muth et al. 2000). Data are insufficient to estimate the number of adults in the lower reach of the Green River (Minckley et al. 1991). Bestgen et al. (2002) estimated that the current population of wild adult razorback sucker in the middle Green River is about 100.

In the upper Colorado River subbasin, the number of razorback sucker captured has decreased dramatically since 1974. The wild population is considered extirpated from the Gunnison River (Burdick and Bonar 1997) and there are only a few scattered adults in the mainstem Colorado River (Osmundson and Kaeding 1991). During a 2-year study (1979–1981), Valdez et al. (1982) captured only 52 individuals, all old adults, in a 465–km reach of the Colorado River from Rifle, Colorado, to Hite, Utah. Thirty-seven (71%) of these fish were found in two abandoned gravel pits in Grand Valley, Colorado, just upstream and downstream of the confluence with the

Table 1. Locations and limits to distribution of razorback sucker in the Colorado River Basin.

| River | Locations | Limits to Distribution |
|---|---|---|
| **Green River Subbasin** | | |
| Green River | Lodore Canyon to Colorado River confluence (580 km); population being augmented | Cold-water releases from Flaming Gorge Dam previously restricted range, but warmed releases may allow for range expansion |
| Yampa River | Craig, Colorado, to Green River confluence (227 km) | Present in low numbers in historic habitat |
| White River | Taylor Draw Dam to Green River confluence (100 km) | Found in low numbers; upstream distribution blocked by Taylor Draw Dam |
| Duchesne River | Lower 2 km above Green River confluence | Found as small aggregations during spring runoff at mouth |
| **Upper Colorado River Subbasin** | | |
| Upper Colorado River | Palisade, Colorado, to Lake Powell inflow (298 km); population being augmented | Found in low numbers; passage by Grand Valley Diversion completed in 1998; Price-Stubb and Government Highline diversion dams restrict upstream distribution; Lake Powell inflow defines downstream distribution |
| Gunnison River | Lower 54 km above Colorado River confluence; population being reestablished through stocking. | Wild population considered extirpated from the river, but fish are being stocked in the lower 54 km above the Colorado River confluence to reestablish the population; Redlands Fishway allows passage since 1996; upstream distribution limited by Hartland Diversion Dam and possibly cold-water releases from the Aspinall Unit |
| **San Juan River Subbasin** | | |
| San Juan River | Shiprock, New Mexico, to Lake Powell inflow (241 km); population being reestablished through stocking | Wild population considered extirpated from the river, but fish are being stocked between Shiprock, NM and Lake Powell inflow (241 km) to reestablish the population; diversion structures block upstream movement; Lake Powell defines downstream distribution |
| **Lower Colorado River Subbasin** | | |
| Lake Mohave | Potential lake-wide distribution; population being augmented | Found only in reservoir |
| Lake Mead | Potential lake-wide distribution | Found only in reservoir but may extend upstream into lower Grand Canyon; cold-water releases from Glen Canyon Dam prevent expansion into upper Grand Canyon |
| Lower Colorado River | Lake Havasu to Davis Dam (96 km) | Stocked fish have not remained in Lake Havasu, but have populated the river between the reservoir and Davis Dam; fish spawned and produced larvae in 2000 and 2001 |
| **Gila River Subbasin** | | |
| Verde River | Limited distribution of hatchery stocks | |
| Salt River | Limited distribution of hatchery stocks | |

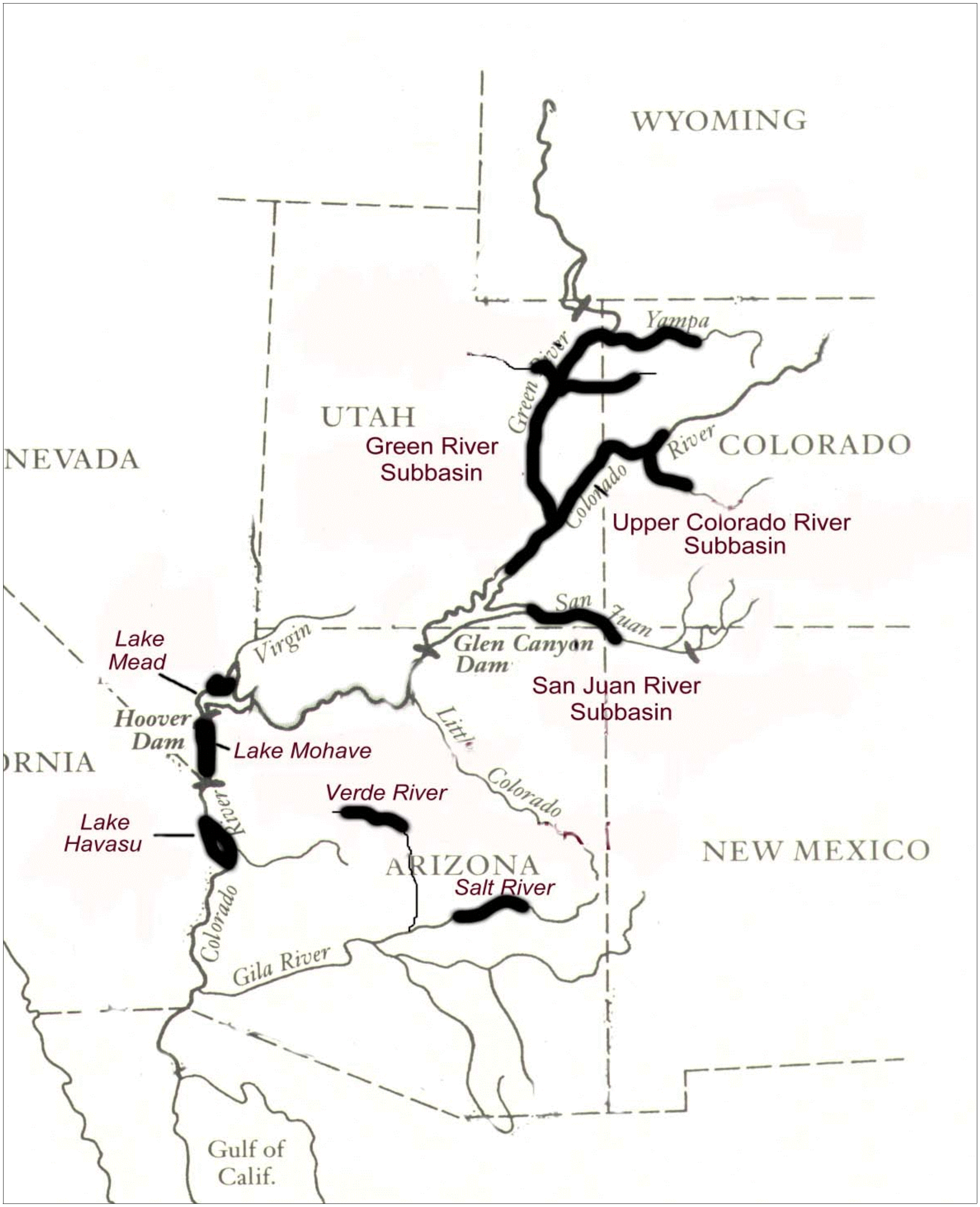


Figure 1. Distribution of wild or stocked razorback sucker in the Colorado River Basin.

Gunnison River. Four fish were captured in Lake Powell; two between Lake Powell and Moab, Utah; two just downstream of Grand Valley; two in the river in Grand Valley; and three between Grand Valley and Rifle. Between 1984 and 1990, despite intensive collecting efforts, only 12 individuals, including some in reproductive condition, were captured in the Grand Valley (Osmundson and Kaeding 1991). No young razorback sucker have been captured anywhere in the upper Colorado River since the mid-1960s (Osmundson and Kaeding 1991).

Scientifically documented records of wild razorback sucker in the San Juan River are limited to two fish captured in a riverside pond near Bluff, Utah, in 1976, and one fish captured in the river in 1988, also near Bluff (Ryden 2000). No wild razorback sucker were found during the 7-year research period (1991–1997) of the SJRRIP (Holden 1999). Large numbers were anecdotally reported from a drained pond near Bluff in 1976, but no specimens were preserved to verify species. Hatchery-reared razorback sucker, especially larger fish (> 350 mm), introduced into the San Juan River in the 1990s have survived into subsequent years and reproduced, as evidenced by recapture data and collection of larval fish (Ryden 2000).

Currently, the largest concentration of razorback sucker remaining in the entire Colorado River Basin is in Lake Mohave. These fish were reported as common to abundant when the reservoir was filling in the 1950's, with the number of adults appearing to remain fairly stable through the 1970's and 1980's (Minckley et al. 1991). Minckley (1983), however, found no evidence of recruitment to the adult population in Lake Mohave since before 1964 despite documented spawning and the presence of larval fish. This failure to recruit has been attributed primarily to predation of larvae by nonnative fishes (Minckley et al. 1991; Burke 1994; Horn 1996; Pacey and Marsh 1998a, 1998b). Estimates of the wild stock in Lake Mohave, now old and senescent, have dropped precipitously in recent years from 60,000 as late as 1991 to 25,000 in 1993 (Marsh 1993; Holden 1994) to about 9,000 in 2000 (personal communication, T. Burke, U.S. Bureau of Reclamation). The Lake Mohave NFWG captures larvae annually for rearing in sheltered environments and release back to the wild population. Until recently, efforts to introduce young razorback sucker into Lake Mohave had failed because of predation by nonnative species (Minckley et al. 1991; Clarkson et al. 1993; Burke 1994). The protocol now used in the lower basin, which is to introduce relatively large (> 250 mm TL) razorback sucker from grow-out facilities, has resulted in improved survival rates (Burke 1994; Pacey and Marsh 1998a; Jahrke and Clark 2000). Survival of these fish has been reported, and recruitment to adults is expected starting in the year 2000.

It is estimated that there are more than 1,000 razorback sucker in the 60-mile reach of the lower Colorado River between Davis Dam and Lake Havasu, with evidence of reproduction (Mueller 2001). These individuals do not include the fish in Lake Havasu.

In Lake Mead, razorback sucker were reported as common into the 1960s, but numbers were noticeably reduced by the 1970's, and the species is now considered rare (Minckley 1973; Bozek et al. 1991). Holden et al. (1999a, 1999b) reported finding adult fish, many in spawning condition; larval fish; and a few juveniles in Lake Mead, primarily in Vegas Bay or Echo Bay, two documented spawning sites in the reservoir. They estimated the combined population of these two spawning aggregations at around 400 adults. Recently collected age-growth data showed fish at about 20–25 years of age, indicating recent recruitment (Ruppert et al. 1999).

Between 1981 and 1990, more than 10 million hatchery-produced razorback sucker were released into historic habitat in the Verde and Salt rivers in Arizona, where the natural population had been extirpated (Hendrickson 1994). These releases were made prior to the listing of the razorback sucker in 1991. Low short-term survival and no long-term survival were reported from these releases, primarily because of predation by nonnative fishes (Maddux et al. 1993). Since 1994, 17,371 razorback sucker have been stocked into the Verde River. Numerous fish have been recaptured, and survival up to 2 years has been documented. In addition, ripe males have been encountered in the Verde River, but no evidence of reproduction or recruitment has been found (personal communication, D. Shroufe, Arizona Game and Fish Department).

### *3.1.3 Populations of razorback sucker as redundant units*

Maintaining several populations with relatively independent susceptibility to threats is an important consideration in the long-term viability of a species (Shaffer 1987; Goodman 1987). These redundant populations provide security in case of a catastrophic event or repeated year-class failure. The positive effect of relatively independent populations can be demonstrated by the following examples. Consider that a single population has a probability of extinction from a catastrophic event of 10% in 200 years. If two populations are independent, the probability of both going extinct is 1% ($0.1^2$). For three populations, the probability reduces to 0.1% ($0.1^3$). Even with an extinction probability of 25% for one population, the probability of extinction for two and three populations is 6.3% and 1.6%, respectively (Casagrandi and Gatto 1999).

An important aspect of recovery for razorback sucker is the establishment of several viable populations that are independently susceptible to catastrophic events. Maintenance of these populations would constitute sufficient redundancy as protection against threats and catastrophic events. If one population is severely depleted or eliminated by a catastrophe, other viable, self-sustaining populations will provide a source of fish and genetic material for restarting an extirpated population.

### *3.1.4 Razorback sucker as a metapopulation*

The metapopulation concept is a natural phenomenon that should be considered when evaluating species persistence. A metapopulation is defined as a network of populations or subpopulations that have some degree of intermittent or regular gene flow among geographically separate units occupying habitat patches (Meffe and Carroll 1994). Populations that make up a metapopulation exist along a continuum of connectedness, with no clear break points, from totally isolated units to those that experience regular and high gene flow (Ehrlich and Murphy 1987; Harrison et al. 1988). Connectedness among units of a metapopulation may vary seasonally or annually (U.S. Fish and Wildlife Service 1995), and the best way to identify population units is that they have some ecological and evolutionary significance (Hanski and Gilpin 1997). Under metapopulation dynamics, habitat patches that become unoccupied due to local extirpations may become repopulated by dispersing individuals from other subpopulations. Metapopulations depend on the ability of individuals to disperse and repopulate empty patches in a manner timely enough to ensure that sufficient numbers of patches always contain viable subpopulations. The role of metapopulations in razorback sucker population dynamics can only be determined after populations become established.

## 3.2 Carrying Capacity

Carrying capacity is the theoretical size of a population that can be sustained by the existing environment, and is determined by population demographics and resource limitations (i.e., limiting factors), including habitat. Functional carrying capacity is the population at its equilibrium state in the presence of resource limitations, and is determined as the level where births equal deaths, or lambda ($\lambda$) is equal to 1.0 (Begon et al. 1990). Potential carrying capacity is the maximum possible population size with resource limitations minimized or removed.

Carrying capacity of razorback sucker is not expected to be the same for different populations because physical habitat (e.g., river channel, flow, and cover), chemical constituents (water quality), and biological components (e.g., food and predators) are likely to vary among river reaches. Hence, the same or even similar numbers and densities of fish in each population should not be expected for recovery. Carrying capacity, as a function of recovery, must be considered on its own merits for recovery of each population. Numbers of razorback sucker in the wild are so low that carrying capacity cannot be determined at this time, therefore demographic recovery criteria may need to be modified as populations are established and information on carrying capacity is developed.

## 3.3 Genetic Viability

Genetic viability describes the pool of genetic diversity adequate to allow a population of animals to survive environmental pressures that may exceed the limits of developmental plasticity (Frankel 1983). Genetically viable populations maintain 90% of the genetic diversity present in the ancestral (pre-disturbance) population for 200 years (Soulé 1980; Soulé and Wilcox 1980; Soulé and Simberloff 1986). Genetic variability consists of within-population genetic diversity and genetic variation found among linked populations or stocks (Meffe 1986; Meffe and Carroll 1994). The risk with razorback sucker is erosion of genetic variability in local or regional populations, which could result in increased extinction probabilities and lead the population to “extinction vortices” (Gilpin and Soulé 1986). Genetic concepts that were considered are summarized in Box 3.

The razorback sucker appears to be a highly diverse species, displaying many mtDNA genotypes. Based on restriction endonuclease analysis of mitochondrial DNA (mtDNA) from fish throughout the Colorado River Basin, it was determined that fish from Lake Mohave displayed the highest degree of genetic variability. Moving from south to north through the Colorado River Basin, genetics of fish appear to be progressively less diverse and possess fewer unique genotypes. Most fish sampled throughout the basin exhibited genotypes identical to those in the Lake Mohave fish; unique genotypes were rarely found (Dowling and Minckley 1993).

**Box 3. Genetics Concepts and Considerations**

- Genetic viability describes the pool of genetic diversity adequate to allow a population of animals to survive environmental pressures that may exceed the limits of developmental plasticity.
- Genetic variability consists of within-population genetic diversity and genetic variation found among linked populations.
- Genetic effective population size ($N_e$) is the number of individuals contributing genes to the next generation.
- Rate of inbreeding is an index of the amount of genetic exchange among closely related individuals and is of particular importance because it may result in offspring that are sterile or inviable after one to several generations.
- $N_e$ of at least 50 adults avoids inbreeding depression and is necessary for conservation of genetic diversity in the short-term; $N_e$ of 500 is needed to avoid serious long-term genetic drift; $N_e$ of 1,000 provides a conservative estimate beyond which significant additional genetic variation is not expected.
- Minimum viable population (MVP) is defined as a population that is sufficiently abundant and well adapted to its environment for long-term persistence without significant artificial demographic or genetic manipulations.

Hybridization between razorback sucker and flannelmouth sucker was reported as early as 1889 (Hubbs and Miller 1953) and continues to be reported in recent years (Suttkus et al. 1976; Kidd 1977; McAda and Wydoski 1980; Buth et al. 1987, 1995; Maddux et al. 1987; Minckley et al. 1991; Valdez and Ryel 1995; Douglas and Marsh 1998).

### *3.3.1 Genetic effective population size*

One way to judge genetic viability is through consideration of "genetic effective population size" ($N_e$), which is the number of individuals contributing genes to the next generation (Crow and Kimura 1970; Gilpin and Soulé 1986; Soulé 1987; Allendorf et al. 1997). $N_e$ was derived in order to gauge the number of adults needed in a population to maintain genetic viability. The concept of $N_e$ was defined by Wright (1931) as the size of an ideal population whose genetic composition is influenced by random processes in the same way as the real population. Low heterozygosity is the dynamic result of low $N_e$, and $N_e$ likely differs by species (Meffe 1986). The concept of $N_e$ was used to determine if wild populations are at risk genetically, but lack of genetic structural characterization with functional relationships for razorback sucker precludes a specific determination of $N_e$ at this time. In the absence of this information, $N_e$ for razorback sucker was derived from principles in conservation genetics by using the "50/500 rule" (Franklin 1980). It has been suggested that a minimum genetic effective population size of 50 is required to avoid inbreeding depression (Soulé 1980), and a minimum genetic effective population size of 500 is required to reduce long-term genetic drift (Franklin 1980). Lynch (1996) suggested an $N_e$ of 1,000 as the number of adults beyond which significant additional genetic variation is not expected. An $N_e$ of 500 is commonly used for fishes (Waples 1990; Bartley et al. 1992;

Allendorf et al. 1997) and other vertebrate species (Mace and Lande 1991; Ralls et al. 1996). No wild, self-sustaining populations of razorback sucker exist that provide sorting of alleles to maintain natural genetic variability. Where recovery relies on artificially reared select individuals, it is necessary to start populations or augment existing populations with large numbers of individuals to ensure genetic variability. Without wild populations, genetic viability is not assured, therefore, razorback sucker require an $N_e$ of 1,000, representing the number of adults beyond which significant additional genetic variation is not expected (Lynch 1996). Recent research by fish geneticists support use of the 50/500 rule (Reiman and Allendorf 2001). An important consideration to genetic viability is maintaining natural connectedness and potential for gene flow among populations, regardless of size (Reiman and Dunham 2000).

It is important to note that the number of individuals in a population required to achieve a genetic effective population size may be several times greater than the genetic effective population size (Frankel and Soulé 1981). Sex ratio and proportion of breeding individuals in the population are two important considerations in deriving the number of individuals necessary to support $N_e$. A 3:1 male to female ratio is used as the effective sex ratio for razorback sucker based on a consensus decision of biologists (Lentsch et al. 1998), although a 1:1 ratio was observed for spawning razorback sucker in Lake Mohave (personal communication, P. Marsh, Arizona State University). To maintain an $N_e$ of 1,000 with a 3:1 sex ratio, the total number of breeding adults ($N_b$) must be increased according to the following relationship:

$$N_e = 4M_bF_b/(M_b+F_b) \qquad [1]$$

where: $M_b$ = number of breeding males,
$F_b$ = number of breeding females, and
$N_b = M_b + F_b$.

The number of breeding males ($M_b$) needed is 1,000 and the number of breeding females ($F_b$) is 333 for a total of 1,333 adults needed to maintain an $N_e$ of 1,000. Hence, according to Equation [1]:

$$N_e = 4(1{,}000)(333)/1{,}333 = 999 \text{ (approximately 1,000)} \qquad [2]$$

If all adults in a population breed every year and contribute genes to the following generation, some minimum number of adults ($N_g$) would equal $N_e$. However, as with most populations, it is believed that not all razorback sucker spawn every year or contribute genes to the following generation, and hence, $N_g$ is not equal to $N_e$. It is important to determine a ratio of genetic effective population size ($N_e$) to minimum population size ($N_g$), or $N_e/N_g$.

For various fish species (rainbow trout, *Oncorhynchus mykiss*; chinook salmon, *O. tshawytscha*; white seabass, *Atractoscion nobilis*), the ratio $N_e/N_g$ varies from 0.013 to 0.90 (Table 2; Bartley et al. 1992; Avise 1994; Hedrick et al. 1995; Allendorf et al. 1997) for an overall average of about 0.30, which is the ratio reported for chinook salmon (McElhany et al. 2000) and other Pacific salmon species (Waples et al. 1990a, 1990b). This overall average ratio for fishes of 0.30 was used to determine the number of adult razorback sucker needed to support an $N_e$ of 1,000. Mace and Lande (1991) reported that the genetic effective population size is typically 20–50% of the actual population size.

Table 2. Estimates of effective/actual population size ($N_e/N_g$) ratios for various fish species.

| Species | $N_e/N_g$ | Reference |
|---|---|---|
| Sea bass (*Atractoscion nobilis*) | 0.27–0.40 | Bartley et al. (1992) |
| Coho salmon (*Oncorhynchus kisutch*) | 0.24 | Simon et al. (1986) |
| Rainbow trout (*Oncorhynchus mykiss*) | 0.90 | Bartley et al. (1992) |
| Chinook salmon (*Oncorhynchus tshawytscha*) | 0.013–0.043 | Bartley et al. (1992) |
| Chinook salmon (*Oncorhynchus tshawytscha*) | 0.30 | McElhany et al. (2000) |

Using an $N_e$ of 1,000, a 3:1 sex ratio , and an $N_e/N_g$ ratio of 0.30, an estimated $N_g$ of 4,443 was derived as the estimated number of adult razorback sucker necessary to maintain a genetic effective population size in the wild. This approach does not imply that existing populations should be allowed to decrease to this level; the estimate of 4,443 is used as a gauge to evaluate genetic viability of isolated populations.

A conservative approach for determining $N_g$ was used in order to account for unknowns in genetic diversity of the species. At best, using a mixture of wild stocks with low remaining genetic diversity and hatchery stocks with reduced diversity, will result in populations with less than the necessary genetic diversity for their environment, similar to a founder effect (Simberloff and Wilson 1970). It may take several generations following reintroductions for allele shifts to produce a gene pool most suitable to the environment.

### *3.3.2 Minimum viable population*

Genetic effective population size provides a gauge for genetic viability but does not necessarily account for demographic viability. The concept of a minimum viable population (MVP) is defined as a population that is sufficiently abundant and well adapted to its environment for long-term persistence without significant artificial demographic or genetic manipulations (Shaffer 1981; Soulé 1986, 1987; Soulé and Simberloff 1986). Meffe and Carroll (1994) define an MVP as *"the smallest isolated population size that has a specified percent chance of remaining extant for a specified period of time in the face of foreseeable demographic, genetic, and environmental stochasticities, plus natural catastrophes."* Use of MVP does not mean that populations should be allowed to drop to these levels, but is used to assess their genetic and demographic viability. It must be recognized that some populations of any wild animal species may be below an MVP, as dictated by carrying capacity. It cannot be expected that every population will exceed an MVP; linkages to other populations help to keep smaller populations viable. As stated by Thomas (1990), *"There is no single 'magic' population size that guarantees the persistence of animal populations."* Thomas (1990) also stated that MVPs are rarely lower than a few 100 individuals and often correspond to an actual population count of about 1,000.

A minimum viable population size of 5,800 adults was derived by adding 30% to the $N_g$ of 4,443 to account for an estimate of the average annual mortality of adult razorback sucker (4,433 x 1.30 = 5,763 or about 5,800; Box 4; Modde et al. 1996). An average annual adult mortality factor was added to buffer against an event that may result in recruitment failure for a year. The concept of adding a mortality factor to a genetically viable population as demographic security is taken from recovery criteria established for the southern sea otter, in which the estimated mortality from exposure to simulated oil spills was added to the estimate of $N_g$, based on an $N_e$ of 500 (Ralls et al. 1996).

**Box 4. Computation of Minimum Viable Population (MVP)**

$$N_g = N_e/(N_e/N_g)$$

where: $N_e$ = genetic effective population size, 1,330
$N_e/N_g$ = proportion of adults contributing genes to next generation; ~0.30 for most fish

therefore: $N_g = 1{,}330/0.30$
$N_g = 4{,}433$

hence: MVP = 4,433 x 1.30 = 5,763 (rounded to 5,800)
where: 1.30 compensates for annual adult mortality of 30%

# 4.0 THREATS TO RAZORBACK SUCKER BY LISTING FACTOR

The razorback sucker was designated as an endangered species under a final rule published on October 23, 1991 (56 FR 13374). The species was listed as a result of a petition for the Service to conduct a status review of the razorback sucker filed on March 14, 1989, by the parties of the Sierra Club, National Aububon Society, The Wilderness Society, Colorado Environmental Coalition, Southern Utah Wilderness Alliance, and Northwest Rivers Alliance (54 FR 33586) . The petition requested the Service to list the razorback sucker as an endangered species because it has *"...suffered a considerable population decline..." and "...that natural recruitment has not been documented in recent times..."*. The petition attributed the decline of the razorback sucker *"...to predation by exotic fish and dams and other water development projects and diversions that have partitioned the once free-flowing river system into disjunct impoundments and tailwaters."* The final rule for determination of the razorback sucker as an endangered species (56 FR 54957) stated that *"Little evidence of natural recruitment has been found in the past 30 years, and numbers of adult fish captured in the last 10 years demonstrate a downward trend relative to historic abundance. Significant changes have occurred in razorback sucker habitat through diversion and depletion of water, introduction of nonnative fishes, and construction and operation of dams."* Additionally, the Recovery Plan stated that *"Extensive water development projects have depleted flow, altered flow regimes, changed water quality, and fragmented habitat. At the same time, the nature and composition of the fish community has been altered dramatically by the introduction of many nonnative fish species. Predation by nonnative fishes and loss of habitat are primary reasons for the virtual failure of recruitment in razorback sucker populations."*

Hence, the primary threats to razorback sucker populations are streamflow regulation and habitat modification (including cold-water dam releases, habitat loss, and blockage of migration corridors); competition with and predation by nonnative fish species; and pesticides and pollutants (Box 5). These threats are associated with the five listing factors (see section 2.1), and a summary of each is presented in the following sections. Site-specific management actions and objective, measurable criteria associated with five recovery factors to minimize or remove threats are provided in section 5.0.

**Box 5. Primary Threats To Razorback Sucker**

- Streamflow regulation.
- Habitat modification.
- Predation by nonnative fish species.
- Pesticides and pollutants.

## 4.1 Listing Factor (A): The Present or Threatened Destruction, Modification, or Curtailment of Its Habitat or Range

Streamflow regulation and associated habitat modification are identified as primary threats to the razorback sucker. Regulation of streamflows in the Colorado River Basin is manifested as reservoir inundation of riverine habitats and changes in flow patterns, sediment loads, and water temperatures. For example, streamflow regulation has generally reduced the magnitude of spring peak flows and increased the magnitude of summer–winter base flows. Since 1950, annual peak flows of the Colorado River in occupied razorback sucker habitat upstream of Westwater Canyon have decreased by 29–38% (Van Steeter and Pitlick 1998). Flows of the Green River at Jensen, Utah, downstream of one of the principal spawning areas of razorback sucker, have decreased by 13–35% during spring and increased by 10–140% during summer through winter due to regulation by Flaming Gorge Dam (Muth et al. 2000). Peak discharge of the San Juan River during the post-dam period (1962–1991) averaged 54% of the spring peak during the pre-dam period (1929–1961), and median monthly flow for the base-flow months of August through February averaged 168% of the pre-dam period (Holden 1999). The life history of the razorback sucker is closely linked to the highly variable conditions of the Colorado River, especially streamflow (see Appendix A). Adults spawn over clean cobble bars during spring runoff, and emerging larvae are transported to highly productive floodplain habitats freshly inundated by spring floods. Loss or reduction of spring flow peaks together with channelization of the river corridor have greatly reduced the extent of these floodplain nurseries and virtually eliminated all successful reproduction and recruitment.

The razorback sucker was first reported in decline following a period of dam construction throughout the Colorado River Basin. Starting with Hoover Dam in 1935, numerous dams were constructed that fragmented and inundated riverine habitat; released cold, clear waters; altered ecological processes; affected seasonal availability of habitat; and blocked fish passage. Reservoirs formed by these dams were stocked with a variety of nonnative fishes for recreational fisheries, and these fishes preyed upon and competed with the native fishes. In the 1960's, major dams were also constructed in the upper basin, primarily through the Colorado River Storage

Project (CRSP) Act, including Flaming Gorge Dam (1962) on the Green River, Navajo Dam (1962) on the San Juan River, the Aspinall Units (1963) on the Gunnison River, and Glen Canyon Dam (1963) on the Colorado River. The decline of the species throughout the basin is attributed largely to extensive habitat loss, modification, and fragmentation, and blocked fish passage associated with dam construction and operations. Following the dams of the CRSP, fewer and smaller dams were constructed on tributaries, including McPhee Dam (1985) on the Dolores River and Taylor Draw Dam (1987) on the White River. Dams have not been constructed within occupied habitat of razorback sucker since 1987, and the threat of dam construction has been minimized considerably.

Total razorback sucker habitat lost to reservoir inundation in the upper basin is about 700 km, including Flaming Gorge Reservoir on the Green River (160 km), Lake Powell (320 km on the Colorado River and 120 km on the San Juan River), and Navajo Reservoir on the San Juan River (100 km). Small numbers of age-0 and juvenile razorback sucker are found seasonally in the Colorado River and San Juan River inflows to Lake Powell, but adults are rarely caught in this reservoir. Although large numbers of razorback sucker have been reported historically from lower basin reservoirs, such as Lake Mead, Lake Mohave, and Lake Havasu, numbers have declined in these environments because of lack of reproduction and recruitment sufficient to replace old and dying adults. These reservoirs became sinks for razorback sucker that once inhabited local riverine regions.

Cold-water releases have eliminated most native fishes from river reaches immediately downstream of dams, except for small numbers of flannelmouth sucker (*Catostomus latipinnis*), bluehead sucker *(C. discobolus*), and speckled dace (*Rhinichthys osculus*) that remain in some tailwaters. River temperatures have been modified from seasonal lows of near freezing and highs of nearly 30°C to relatively constant dam releases of about 4–13°C. Depending on dam elevation, time of year, and river volume, river temperatures may not equilibrate with atmospheric temperatures for nearly 400 km downstream (as in the Colorado River below Glen Canyon Dam). These cold releases have caused reproductive failure and slowed growth of the warm-water native fishes. Penstock modifications on Flaming Gorge Dam in 1976 (Holden and Selby 1979; Holden and Crist 1981) allowed for warmed releases down the Green River beginning in 1978. These warmed releases have provided more suitable water temperatures for several species of native fishes in Lodore Canyon (Bestgen and Crist 2000) and may allow for expansion of razorback sucker when reproduction and recruitment of the species are restored. In the Gunnison River, warming releases from Aspinall Unit dams could provide suitable temperatures for razorback sucker upstream of Delta, Colorado. Only 10 razorback sucker were documented from Grand Canyon from 1944 to 1990 (Valdez 1996), indicating that this species was not a resident of this canyon region, but perhaps a transient moving to and from spawning and feeding areas (Douglas and Marsh 1998). Cold releases from dams probably contributed to the decline of the razorback sucker, maintaining water temperatures too cold for spawning, egg incubation, and survival of embryos.

Razorback sucker were once abundant throughout most of the Colorado River Basin (Jordan and Evermann 1896; Minckley 1973; Sigler and Miller 1963), but the species now inhabits only about 25% of its original range (59 FR 13374). A major cause of decline has been loss of a contiguous complement of habitats used by the various life history phases. Adult razorback sucker can migrate considerable distances to and from spawning sites (Tyus and Karp 1990). The species requires a variety of habitats in different river regions in order to complete its life cycle. Historically, the Colorado River Basin was a continuous series of habitats, and the only physical barriers to movement were natural rapids and swift turbulent flows, which were probably only seasonal impediments to fish movement. Since 1905, numerous human-made dams have been constructed throughout the Colorado River Basin, fragmenting their habitat and blocking migration corridors. In the lower basin, 14 major dams have inundated habitat, altered water quality, restricted fish movement, and otherwise altered habitats through the Colorado, Gila, Salt, and Verde rivers since completion of Hoover Dam in 1935; other dams on the Colorado River include Davis, Parker, Palo Verde Diversion, Imperial, and Laguna. Glen Canyon Dam approximately divides the lower from the upper basin and also is a barrier to fish movement.

Ten barriers are identified in the upper basin upstream of Glen Canyon Dam within occupied habitat of razorback sucker (Burdick and Kaeding 1990; Holden 1999; Table 3). Five of these barriers are classified as medium or high-head structures that are partial or seasonal barriers to fish movement or that have been modified to allow passage. The Price-Stubb Diversion presently defines the upper-most distribution of wild razorback sucker in the upper Colorado River; a second structure, the Government Highline Diversion, is immediately upstream. Passage by these diversions could allow the species to expand its range by about 22 km (Osmundson 1999). The Redlands Fishway on the lower Gunnison River has allowed razorback sucker (personal communication, F. Pfeifer, U.S. Fish and Wildlife Service) and other native fishes to move past the Redlands Diversion. A diversion structure on the Yampa River near Craig, Colorado, was recently replaced, in part, to allow unassisted fish passage (Masslich 1993). On the San Juan River, several diversion structures are in historic habitat and act as fish barriers to limit the range of razorback sucker (Masslich and Holden 1996). The Cudei and Hogback diversions have been modified to allow fish passage and work is being done on the PNM Weir; other diversions are being evaluated. Modification of these dams and diversions could allow for considerable range expansion and increases in populations. Furthermore, water withdrawn at diversion structures can entrain razorback sucker and isolate them in canal systems where their survival is potentially low. Diversion structures should be screened (as needed) to minimize or prevent entrainment of at least subadult and adult razorback sucker.

Maintenance of streamflow is important to the ecological integrity of large western rivers (Tyus 1992; Collier et al. 1996; Poff et al. 1997; Schmidt et al. 1998). Life histories of many aquatic species, especially fish, are often specifically tied to flow magnitude, frequency, and timing, such that disruption of historic flows can jeopardize native species. The importance of flow management to the endangered fishes of the Colorado River is recognized (Tyus 1992; Stanford 1994). Enhancing natural temporal and spatial habitat complexity through flow and temperature management is the basis for benefitting the endangered fishes (Osmundson et al. 2000b).

Table 3. Existing dams and diversion structures within habitat occupied by wild or stocked razorback sucker.

| River | Structure | Current Status | Access to Suitable Habitat |
|---|---|---|---|
| Upper Colorado River | Grand Valley Diversion | Year-around passage completed in 1998 | Passage adds 5 km additional habitat up to Price-Stubb Diversion |
| Upper Colorado River | Price-Stubb Diversion | Environmental Assessment to remove or modify in progress | Passage would add about 9 km additional habitat up to Government Highline Diversion |
| Upper Colorado River | Government Highline Diversion | No formal passage proposal | Passage would add 8 km additional habitat |
| Gunnison River | Redlands Diversion | Fishway installed in 1996; successfully passing fish | Passage adds 50 km additional habitat |
| Green River | Tusher Wash Diversion | Passage may be difficult at very low flows | Occupied habitat both up and downstream |
| Yampa River | Craig Diversion | Structure modified in 1992; successfully passing fish | Occupied habitat downstream |
| White River | Taylor Draw Dam | Dam completed in 1983, no current fish passage | Fish have been found downstream of dam in apparent attempt to migrate to habitat upstream of dam |
| San Juan River | PNM Weir | Diversion being modified to allow passage | Fish found below. |
| San Juan River | Cudei Diversion | Diversion has been modified to allow passage | Fish found above and below. |
| San Juan River | Hogback Diversion | Diversion has been modified to allow passage | Fish found above and below |

Flow recommendations have been developed for some river systems in the Upper Colorado River Basin that identify and describe flows with the necessary magnitude, frequency, duration, and timing to benefit the endangered fish species (e.g., Modde and Smith 1995; Osmundson et al. 1995; U.S. Department of the Interior 1995b; Holden 1999; Modde et al. 1999a; McAda 2000 [under revision]; Muth et al. 2000). These flows were designed to enhance habitat complexity (e.g., suitable spawning areas, inundation of floodplain areas) and to restore and maintain ecological processes (e.g., sediment transport, food production) that are believed to be important to the life history of these endangered fishes. Spring peak flows are important to the dynamic sediment processes that maintain in-channel habitat complexity, and prevent vegetation encroachment and channel narrowing. For example, cobble and gravel deposits used for spawning are relatively permanent features formed at high flows. Lower peak flows in subsequent years result in deposition of fine sediments over cobble and gravel deposits. Peak flows, whose timing coincides with the natural runoff cycle, are needed to ensure that suitable sites, cleansed of fine sediments, are available during the spawning period. Conversely, low and relatively stable base flows in summer, fall, and winter provide stable, warm, and productive nursery habitats for young fish.

Flows necessary to restore and maintain required habitats of razorback sucker mimic the natural hydrograph and include spring peak flows and summer–winter base flows. Habitats used by adults include deeper runs, eddies, backwaters, and flooded off-channel environments in spring; runs and pools often in shallow water associated with submerged sandbars in summer; and low-velocity runs, pools, and eddies in winter (see Appendix A for details on habitat requirements). Spring migrations by adult razorback sucker were associated with spawning in historic accounts, and a variety of local and long-distance movements and habitat-use patterns and have been documented. Spawning occurs over bars of cobble, gravel, and sand substrates during spring-runoff flows at widely ranging flows and water temperatures (typically greater than 14$^{o}$C). Young require nursery environments with quiet, warm, shallow water such as tributary mouths, backwaters, or inundated floodplain habitats. Floodplain areas inundated and temporarily connected to the main channel by spring peak flows appear to be important habitats for all life stages of razorback sucker, and the seasonal timing of razorback sucker reproduction suggests an adaptation for utilizing these habitats. Spring peak flows must be of sufficient magnitude to inundate floodplain habitats and timed to occur when razorback sucker larvae are available for transport into these flooded areas. High spring flows also maintain channel and habitat diversity, flush sediments from spawning areas, rejuvenate food production, form gravel and cobble deposits used for spawning, and rejuvenate backwater nursery habitats that are maintained by base flows. In addition, low, relatively stable base flows reduce flooding of low-velocity habitats and may reduce the breakup of ice cover in overwintering areas (McAda 2000; Muth et al. 2000).

Flow recommendations have been developed that specifically consider flow-habitat relationships within occupied habitat of razorback sucker (see section 3.1.2; Table 1) in the upper Colorado River (Osmundson et al. 1995; McAda 2000), Gunnison River (McAda 2000), Yampa River (Modde and Smith 1995; Modde et al. 1999a), Green River (Muth et al. 2000), and San Juan River (Holden 1999). These flow recommendations will be evaluated and revised (as necessary) as part of an adaptive-management process, and flow regimes to benefit the endangered fishes will be implemented through multi-party agreements or by other means (see section 4.4).

## 4.2 Listing Factor (B): Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

Overutilization of razorback sucker for commercial, recreational, scientific, or educational purposes is not considered a threat to the species, either presently or historically. This factor will be reevaluated and, if necessary, actions to ensure adequate protection will be identified before downlisting and attained before delisting.

Razorback sucker have no commercial or recreational value and are not sought by commercial fishermen or anglers. Some fish may be incidentally caught when recreational angling for other sympatric species, but the number of native fish harmed or killed is believed to be insignificant based on creel surveys by the Colorado Division of Wildlife (personal communication, T. Nesler, Colorado Division of Wildlife). All angler access points near occupied habitat are posted with signs advising anglers to release any endangered fish unharmed.

Collection of razorback sucker for scientific or educational purposes is regulated by the Service under Section 10(a) of the ESA. Scientific collecting permits are issued to investigators conducting legitimate scientific research, and "take" permits are issued where a reasonable loss of fish is expected. Permits to collect razorback sucker for educational purposes are normally not requested but are regulated by the same provisions of the ESA.

## 4.3 Listing Factor (C): Disease or Predation

### *4.3.1 Diseases and parasites*

Diseases and parasites currently are not considered singly significant in the decline of the razorback sucker (see section A.12 for expanded discussion of parasites), but these factors will be reevaluated and, if necessary, actions will be identified to minimize adverse effects before downlisting. Adequate protection from deleterious diseases and parasites will be attained before delisting.

### *4.3.2 Nonnative fishes*

A large number of nonnative fishes are found in historic and currently occupied habitat of razorback sucker. Many of these are considered predators, competitors, and vectors of parasites and diseases (Tyus et al. 1982; Lentsch et al. 1996; Pacey and Marsh1999; Marsh et al. 2001). Many researchers believe that nonnative species are a major cause for lack of recruitment in razorback sucker (e.g., McAda and Wydoski 1980; Minckley 1983; Tyus 1987; Muth et al. 2000). There are numerous reports of predation of razorback sucker eggs and larvae by common carp (*Cyprinus carpio*), channel catfish (*Ictalurus punctatus*), smallmouth bass (*Micropterus dolomeiui*), largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), green sunfish (*Lepomis cyanellus*), and redear sunfish (*Lepomis microlophus*; Jonez and Sumner 1954; Langhorst 1989; Marsh and Langhorst 1988). Ulmer (personal communication, L. Ulmer, California Department of Fish and Game) observed channel catfish consuming swim-up razorback sucker larvae that were suspended in the mid-water column. Marsh and Langhorst (1988) found higher growth rates in larval razorback sucker in the absence of predators in Lake Mohave, and Marsh and Brooks (1989) reported that channel catfish and flathead catfish (*Pylodictis olivaris*) were major predators of newly stocked razorback sucker in the Gila River. Juvenile razorback sucker (average 171 mm TL) stocked in isolated coves along the Colorado River in California suffered extensive predation by channel catfish and largemouth bass (Langhorst 1989).

Similar effects of predation on razorback sucker are reported from the Upper Colorado River Basin. Lentsch et al. (1996) identified six species of nonnative fishes as existing threats, including red shiner (*Cyprinella lutrensis*), common carp, sand shiner (*Notropis stramineus*), fathead minnow (*Pimephales promelas*), channel catfish, and green sunfish. Small forms, such as adult red shiner, are known predators of larval native fish (Ruppert et al. 1993). Large predators, such as walleye (*Stizostedion vitreum*) and northern pike (*Esox lucius*) also pose a threat to subadult and adult razorback sucker (Tyus and Beard 1990).

A Strategic Plan for Nonnative Fish Control was developed for the Upper Colorado River Basin (Tyus and Saunders 1996) and implemented by the UCRRP in 1997. Some activities include mechanical removal of nonnative fishes through intensive sampling, and modification of habitats used as residential or nursery areas by nonnative fishes. Preliminary results of the control program are inconclusive as to the beneficial effects for razorback sucker. Data from a 7-year research period on the San Juan River suggest that efforts to date were effective in reducing density of large channel catfish, but efforts were not effective in reducing overall abundance of channel catfish in the river (Holden 1999). A positive population response by native fishes to this channel catfish reduction has not been reported (personal communication, San Juan River Basin Recovery Implementation Program, Biology Committee). A strategic control program has also been recommended for Grand Canyon (Valdez et al. 1999b), and a Science Plan is being developed for implementation of nonnative fish removal starting in 2003 (GCMRC 2002).

Removal of nonnative fishes from isolated habitats has become one of the major management actions in recovering the razorback sucker in the lower basin. Efforts to restore the gene pool of fishes in Lake Mohave by capturing and rearing larval razorback sucker have identified predation by nonnative fishes as a major cause of mortality of young fish (Marsh 1987, 1994; Mueller 1995; Mueller et al. 1998). These studies have found increased survival and growth of razorback sucker and bonytail under predator-free environments (Mueller et al. 2000).

Control of the release and escapement of nonnative fishes into the main river, floodplain, and tributaries is also a necessary management action to stop the introduction of new fish species into occupied habitats and to thwart periodic escapement of highly predaceous nonnatives from riverside features. Agreements have been signed among the Service and the States of Colorado, Utah, and Wyoming to review and regulate all stockings within the Upper Colorado River Basin (U.S. Fish and Wildlife Service 1996) in order to reduce the introduction and expansion of nonnative fishes. A Memorandum of Agreement implementing these procedures was signed on September 5, 1996, by the Service and the States and remains in effect through the life of the UCRRP. This agreement regulates releases of nonnative fishes within the 50-year floodplain of the river, and provides security against State or Federal endorsed programs introducing new species into the system or increasing the numbers or distribution of existing species. The agreement also allows the States to regulate and restrict stocking of privately owned ponds. These procedures will also reduce the likelihood of new parasites and diseases being introduced through nonnative fish stockings. Similar procedures need to be developed and implemented in the San Juan River subbasin and the lower basin.

Annual flooding of the river can inundate riverside ponds potentially containing large numbers of green sunfish, black bullhead, largemouth bass, and other nonnative fishes that may escape to the river during high flows (Valdez and Wick 1983). Riverside features determined to be problematic must be either isolated from high river floods, designed to drain annually with the rise and fall of the river, or treated with piscicidal compounds to eradicate nonnative fishes. The Colorado Division of Wildlife is to prepare a Colorado River Fisheries Management Plan (Plan) that will implement a more detailed nonnative fish control effort. The Plan is to be reviewed and approved by the Colorado Wildlife Commission and UCRRP. The Plan will be finalized and implemented by the dates specified in the Recovery Implementation Program Recovery Action

Plan (RIPRAP) of the UCRRP. One aspect of the Plan will be pond reclamation, which can include complete removal of nonnative fish, screening ponds to prevent escapement to the river, and/or reshaping ponds so that they no longer support year-round habitation by nonnative fish.

Another aspect of nonnative fish control in the Colorado River Basin is removal of bag and possession limits on nonnative fishes in designated critical habitat. For example, the State of Colorado has removed bag and possession limits on all nonnative, warm-water sport fishes within critical-habitat reaches of the Colorado and Yampa rivers. Colorado also has agreed to close river reaches to angling where and when angling mortality is determined to be significant to native fishes. The State of Arizona has implemented a similar measure of removing bag and possession limits of nonnative species within designated critical habitat.

Three management actions are identified to reduce the threat of nonnative fishes: high spring flows, nonnative fish control strategies, and stocking agreements. There is documented evidence that high flows temporarily disadvantage nonnative fishes in several ways, including displacement from sheltered habitats, disruption of spawning activities, increased mortality in high mainstem currents, and physical downstream transport of individuals. Studies from the Upper Colorado River (McAda and Kaeding 1989), Green River (Valdez 1990), Yampa River (Muth and Nesler 1993), and Lower Colorado River through Grand Canyon (Hoffnagle et al. 1999; Valdez et al. 2001) showed reductions in densities of small-bodied species of fish (e.g., fathead minnow, red shiner, sand shiner, plains killifish [*Fundulus zebrinus*]) following high flows. On the San Juan River, no evidence exists to support the hypothesis that high flows even temporarily disadvantage nonnatives and promote endangered fish reproduction and recruitment (Holden 1999). Strong year classes of native species (e.g., Colorado pikeminnow [McAda and Ryel 1999], humpback chub [Gorman 1994]) have consistently occurred following high runoff years, and have been attributed to cleansing of spawning gravels and short-term reduction in nonnative fishes. Hence, even a short-term reduction in nonnative fishes could allow increased survival and recruitment of native forms (Tyus and Saunders 1996). Flow recommendations include the provision of high flows, which provide these unsuitable conditions for nonnative fishes and may at least temporarily reduce numbers of these predators and competitors.

Active control programs should be implemented or continued (as needed) for problematic nonnative fishes in razorback sucker nursery habitats such as flooded bottomlands, northern pike in the middle Green River, and channel catfish and flathead catfish in river reaches occupied by razorback sucker. Guidance is not provided in this document with regard to target reduction levels because such criteria may be premature and unreasonable to achieve, or may be easily achieved and exceeded. Little is known with respect to responses by nonnative fish populations to overt control measures, and these must be evaluated as part of nonnative fish control programs. Another unknown aspect of nonnative fish control is the need to maintain control measures indefinitely or periodically over time. These decisions will have to be made from information gained through these control programs during the downlist monitoring period.

## 4.4 Listing Factor (D): The Inadequacy of Existing Regulatory Mechanisms

Implementation of regulatory mechanisms are necessary for recovery of the razorback sucker and to ensure long-term conservation of the species. Regulatory mechanisms affect many aspects of legal protection, such as habitat and flow protection, regulation and/or control of nonnative fishes, regulation of hazardous-materials spills, and angling regulations. Flow regimes to benefit razorback sucker populations must be identified, implemented, evaluated, and revised (as necessary) before downlisting can occur (existing flow recommendations are described in section 4.1). By the time of delisting, legal protection of habitat (including flows) necessary to provide adequate habitat and sufficient range for all life stages of razorback sucker to support recovered populations must be accomplished through various means including instream-flow appropriations, legal agreements, contracts, operating criteria, and/or other means. Additionally, certain States may issue policies that also afford flow protection. As examples, the State of Utah has instituted a policy that subordinates all future water-rights appropriations for the Green River from Flaming Gorge Dam to the Duchesne River confluence for the summer and autumn periods to provide flows to benefit the endangered fish; actions proposed under this policy would not affect pre-existing water rights (Utah Division of Water Rights 1994). Also, the State of Colorado has established two instream-flow rights on the Colorado River under its state instream-flow law.

Before delisting, the primary regulatory mechanism for protection of razorback sucker is through Section 7(a)(2) of the ESA, as administered by the Service. *"Each Federal agency shall, in consultation with and with the assistance of the Secretary, insure that any action authorized, funded, or carried out by such agency... is not likely to jeopardize the continued existence of any endangered species or threatened species or result in the destruction or adverse modification of habitat of such species which is determined by the Secretary, after consultation as appropriate with affected States, to be critical..."* In the Upper Colorado River Basin, the UCRRP provides a mechanism for dealing with Section 7 consultations in a unified manner. The SJRRIP provides a similar consolidated effort for addressing Biological Opinions in the San Juan River, including Navajo Dam. There are currently no formal recovery programs in the lower basin, and Section 7 consultations are addressed on a case-by-case basis. The GCDAMP provides a mechanism for a consolidated effort addressing the Biological Opinion of the Glen Canyon Dam EIS (U.S. Fish and Wildlife Service 1994). The NFWG is an ad hoc group of dedicated volunteers and agency biologists focused on protecting and augmenting the genetic diversity of current native fish populations in Lake Mohave. The goal of the MSCP is to provide a comprehensive mechanism for ensuring regulatory compliance under both Sections 7 and 10 of the ESA for all participating Federal and non-Federal MSCP agencies and entities. Similarly, the MSCP is intended, and is being structured, to provide environmental compliance pursuant to the California Endangered Species Act and California Environmental Quality Act (CEQA). None of the recovery or conservation programs in the Colorado River Basin are regulatory mechanisms that provide permanent, long-term protection for the species after delisting.

In addition to Federal protection under the ESA, razorback sucker are protected by all basin States under categories such as "endangered", "threatened", or "sensitive". This protection prohibits intentional take and keeping or harming in any way any fish captured incidentally, and may need to remain in place after the species is Federally delisted. However, the States do not address the major problem of habitat destruction, and especially streamflow modification. Most States have instream-flow laws that allow "beneficial use" of water left in streams for wildlife, but these laws typically only provide for flow that is the minimum amount necessary to maintain the fishery. With some States, there is also an inherent conflict between management of nonnative sport fish and recovery of endangered fishes. Where valued sport fisheries occur, there is an ongoing dilemma between public demands for maintenance and expansion of fisheries and management actions to conserve and recover endangered fish. There is no immediate solution to the dilemma, but predation by nonnative fishes is clearly identified as a cause for the decline of many of the native Colorado River fishes, and long-term agreements between States and the Service are essential.

After removal from the list of species protected by the ESA, the razorback sucker and its habitat will continue to receive consideration and some protection through the following Federal laws and related State statutes, and will need the provisions to protect habitat previously discussed. The National Environmental Policy Act (NEPA; 42 U.S.C. 4321–4370d) requires Federal agencies to evaluate the potential effects of their proposed actions on the quality of the human environment and requires the preparation of an environmental impact statement whenever projects may result in significant impacts. Federal agencies must identify adverse environmental impacts of their proposed actions and develop alternatives that undergo the scrutiny of other public and private organizations as a part of their decision-making process. Recovery actions identified for razorback sucker are linked to federal actions, which must undergo review under NEPA.

Section 101(a) of the Federal Water Pollution Control Act (i.e., Clean Water Act; 33 U.S.C. 1251–13287) states that the objective of this law is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters and provide the means to assure that *"...protection and propagation of fish, shellfish, and wildlife..."*. This statute contributes in a significant way to the protection of the razorback sucker and its food supply through provisions for water quality standards, protection from the discharge of harmful pollutants, contaminants [Section 303(c), Section 304(a), and Section 402] and discharge of dredge or fill material into all waters, including certain wetlands (Section 404).

The Organic Act (16 USC 1, as amended) provides for management of National Park Service areas in such a manner *"...to promote and regulate the use of the...national parks...which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."* The National Park Service is the largest single jurisdictional land owner in reaches with critical and other occupied habitats for the four Colorado River endangered fishes (Maddux et al. 1993).

The Fish and Wildlife Coordination Act (16 U.S.C. 661–666c) requires that Federal agencies sponsoring, funding, or permitting activities related to water resource development projects request review of these actions by the Service and the State natural resource management agency.

These comments must be given equal consideration with other project purposes. Also, the Federal Land Policy and Management Act (43 U.S.C. 1701–1784) requires that public lands be managed to protect the quality of scientific, ecological, and environmental qualities and preserve and protect certain lands in their natural conditions to provide food and habitat for fish and wildlife.

The need for conservation plans and agreements was identified to provide reasonable assurances that recovered razorback sucker populations will be maintained. These plans are to be implemented after delisting and are intended to assure that relisting does not become necessary. They would be developed to ensure long-term management and protection of the species, and should include (but not limited to) provision of flows for maintenance of habitat conditions required for all life stages, regulation and/or control of nonnative fishes, minimization of the risk of hazardous-materials spills, and monitoring of populations and habitats. Signed agreements among State agencies, Federal agencies, American Indian tribes, and other interested parties must be in place to implement the conservation plans before delisting can occur.

## 4.5 Listing Factor (E): Other Natural or Manmade Factors Affecting Its Continued Existence

### *4.5.1 Hybridization*

The present levels of hybridization among razorback sucker and other catostomids is not considered a threat to the species, but this factor will be reevaluated at downlisting and any necessary actions to reduce deleterious levels of hybridization will be implemented at delisting. A discussion of hybridization is presented in section A.3. Hybridization between razorback sucker and flannelmouth sucker (a native of the Colorado River Basin) apparently occurred historically (Hubbs and Miller 1953). Hybridization with nonnative white sucker (*Catostomus commersoni*) may be problematic for the razorback sucker in some parts of the upper basin. Abundance and distribution of white sucker and numbers of hybrids with flannelmouth and bluehead suckers have increased substantially since about 1980 (Valdez et al. 1982; Masslich 1993). These reports demonstrate the capability for white sucker to hybridize with native Colorado River suckers and suggest likely hybridization with razorback sucker as populations are expanded for recovery.

### *4.5.2 Pesticides and pollutants*

The potential role of pesticides and pollutants in suppressing populations of razorback sucker is not well understood. Pesticides find their way to the Colorado River from agricultural runoff, and other pollutants in the system include petroleum products, heavy metals (e.g., mercury, lead, zinc, copper), nonmetals (i.e., selenium), and radionucleides.

Potential spills of petroleum products threaten wild populations of razorback sucker. For example, numerous petroleum-product pipelines cross or parallel the Yampa River upstream of Yampa Canyon, most of which lack emergency shut-off valves. One pipe ruptured in the late

1980's releasing refined oil into the Yampa River, but the effects of this spill were not documented.

All States have hazardous-materials spills emergency-response plans that provide a quick cleanup response to accidental spills (see section 4.4). These responses may not be sufficiently rapid to minimize deleterious effects to fishes, especially a species like the razorback sucker with site-specific spawning areas. Quick response may, therefore, be inadequate to protect the species and preventive measures must be incorporated into these plans. These preventive measures may include safety shut-off valves on petroleum-products lines in or near the floodplain and filtration systems in case of accidental spills of hazardous materials at bridge crossings above occupied habitats. Identifying and implementing the most reasonable and prudent preventive measures will require a comprehensive review of existing State and Federal hazardous-materials spills emergency-response plans. These preventive measures must be implemented before delisting.

Another cause of degraded water quality is the Atlas Mills tailings pile located on the north bank of the Colorado River near Moab, Utah. In 1998, the Service determined in a final biological opinion that this pile *"...is likely to jeopardize the continued existence of..."* the Colorado pikeminnow and razorback sucker. This biological opinion was withdrawn on February 8, 2001, because of refusal by the Nuclear Regulatory Commission to reinitiate consultation. Section 3405 of the Floyd D. Spence National Defense Authorization Act for Fiscal Year 2001 (P.L. 106-398) requires that the Atlas Mills tailings site be transferred to the Department of Energy for remediation. Congress authorized $300 million for clean-up of the Atlas Mills tailings pile. Remediation is outside of the purview of the UCRRP.

There are two significant threats to endangered fish posed by the Atlas Mills tailings pile. The first is from toxic discharges of pollutants, particularly ammonia, through groundwater to the Colorado River. The second is the risk of catastrophic pile failure, that could bury important nursery areas and destroy other fish habitat. To address the threats posed by the discharge of toxic pollution, whether tailings are reclaimed on site or removed to another location, the groundwater must be cleaned up to the extent necessary to prevent the discharge of ammonia, uranium, and other toxic pollutants into the Colorado River and meet the State of Utah surface-water and groundwater quality standards for fish and wildlife. To assess whether such clean-up has occurred, groundwater-system compliance and measuring points must be established.

Selenium is hypothesized as contributing to the decline of the endangered fishes of the Colorado River Basin (U.S. Fish and Wildlife memorandum, December 22, 1998). It is a water-quality factor that may inhibit recovery by adversely affecting reproduction and recruitment (Stephens et al. 1992; Hamilton and Waddell 1994; Hamilton et al. 1996; Stephens and Waddell 1998; Osmundson et al. 2000a). Selenium concentrations in certain areas of the basin (e.g., Green River near Jensen, Utah; Gunnison River downstream from the Uncompahgre River confluence; and upper Colorado River downstream from Palisade, Colorado) exceed those shown to impact fish and wildlife elsewhere, and, although results are inconclusive as to exposure thresholds that cause specific effects, some studies suggest deleterious effects on razorback sucker and Colorado pikeminnow. The National Irrigation Water Quality Program is addressing selenium issues in the upper basin by implementing remediation projects to reduce selenium levels in areas of critical habitat. The adverse effects of selenium contamination on razorback sucker reproduction and survival of young will be reevaluated before downlisting and necessary protection will be implemented before delisting.

# 5.0 RECOVERY GOALS

The following are site-specific management actions and objective, measurable recovery criteria for the razorback sucker presented by the two recovery units, i.e., the upper basin (including the Green River and upper Colorado River subbasins) and the lower basin (including the mainstem and its tributaries from Glen Canyon Dam downstream to the southerly International Boundary with Mexico). The razorback sucker was listed prior to the 1996 DPS policy, and the Service may conduct an evaluation to designate DPSs in a future rule-making process. Steps for downlisting and delisting presented in this section are consistent with provisions specified under Section 4(a)(1), Section 4(b), Section 4(c)(2)(B), and Section 4(f)(1) of the ESA (see section 2.0 of this document). The five recovery factors (i.e., Factor A, Factor B, etc.) were derived from the five listing factors (see section 2.1) and state the conditions under which threats are minimized or removed. For each recovery factor, management actions and tasks are identified that minimize or remove threats to the razorback sucker. Under objective, measurable recovery criteria, demographic criteria and recovery factor criteria are presented for downlisting and delisting. Generally, for each downlisting criterion there is a corresponding delisting criterion. Reclassification can be considered when appropriate recovery criteria are met.

Anthropogenic changes in the lower basin have extensively modified the riverine ecosystem, including native-fish habitats. Therefore, recovery goals in the lower basin are based on a limited amount of historic habitat and taking aggressive actions (e.g., stocking large numbers of adults) that allow for the establishment and maintenance of populations in riverine and/or repatriated habitats (e.g., riverside habitats, such as oxbows, depressions, bottomlands, that are connected where feasible to the mainstem Colorado River).

## 5.1 Requirements and Uncertainties Associated with Recovery Goals

### *5.1.1 Demographic criteria and monitoring*

Demographic criteria that describe numbers of populations and individuals (adults and juveniles) for downlisting and delisting are presented for upper and lower basin recovery units. These criteria require four genetically and demographically viable, self-sustaining populations (two in each recovery unit), based on requirements of no significant decline in numbers of adults for each population and recruitment equal to or exceeding adult mortality. In addition, a genetic refuge needs to be maintained in Lake Mohave of the lower basin recovery unit (based on the majority opinion of lower basin biologists, the number of adults for maintaining this refuge is 50,000).

It is anticipated that self-sustaining populations of razorback sucker will be established over the next 15 years, during which time population dynamics and responses to management actions will be evaluated. A 5-year monitoring period is required for downlisting, and a 3-year monitoring period beyond downlisting is required for delisting. The downlist monitoring period begins with the first reliable estimates for all populations acceptable to the Service once self-sustaining populations have been established (i.e., progeny are recruiting). The downlist and delist monitoring periods are expected to be continuous, and reclassification cannot be considered until each population has been monitored for the required period of time. The total 8-year monitoring period is equivalent to approximately one generation time for razorback sucker, and is considered sufficient to determine if populations are stable, increasing, or decreasing. Generation time is equal to the mean adult age and is computed as the average age of attaining sexual maturity; i.e., $age_{sex\ maturity}$ plus (1/d), where d is equal to death rate (Seber 1982; Gilpin 1993). For razorback sucker, the age of attaining sexual maturity is estimated at 4–5 years and the adult survival rate is 0.70 (d=1-0.70); hence, generation time is 5 + [1/(1-0.70)] or approximately 8. It is important to note that under Section 4(g)(1) of the ESA, *"The Secretary shall implement a system in cooperation with the States to monitor effectively for not less than five years the status of all species which have recovered to the point at which the measures provided pursuant to this Act are no longer necessary..."*. Hence, populations would be monitored for at least 5 additional years after delisting.

The Service considers a reliable estimate as one that is based on a multiple mark-recapture model. Direct enumeration of fish populations is not feasible in turbid rivers, and removal estimates are unreliable because of the difficulty of blocking reaches of large rivers to meet the model assumption of no migration. Instead, closed-population, multiple mark-recapture estimators (Otis et al. 1978; Burnham et al. 1987; Chao 1989; Osmundson and Burnham 1998) are recommended for deriving population point estimates and to guide development of sampling designs that conform to these models. The accuracy and precision of each point estimate will be assessed by the Service in cooperation with the respective recovery or conservation programs, and in consultation with investigators conducting the point estimates and with qualified statisticians and population ecologists. If, for example, an estimate is made that is considered unreliable (i.e., lacks precision and accuracy) because of poor sampling conditions or other causes, a determination will be made if an additional estimate is needed in the following year in order to accurately assess if downlisting or delisting criteria are met. Field sampling methodologies should be developed and refined to attain a balance between the need for accurate and precise population estimates while minimizing stress to fish from excessive handling.

Monitoring must be designed to determine if the demographic criteria are being met. At least three point estimates are needed for each of the four established razorback sucker populations to downlist, and at least two more estimates are needed to delist. In order to ensure no net loss in each population, the trend in adult (age 4+; ≥400 mm TL; McAda and Wydoski 1980) point estimates cannot decline significantly; i.e., slope is not significantly less than zero over the trend period ($p \leq 0.05$), requiring that the population is either stable or increasing during the monitoring period. Also, mean estimated recruitment of age-3 (300–399 mm TL; McAda and Wydoski 1980) naturally produced fish in each population must equal or exceed mean annual adult mortality (i.e., ≥30%). This criterion requires that each population is reproducing, recruiting, and self-sustaining. To meet the requirement of genetically and demographically viable, self-sustaining populations, each point estimate for each population must exceed 5,800 adults (MVP; see section 3.3.2). In addition to the demographic criteria, adequate habitat and sufficient range are required to support recovered populations. Recovery goals allow for maintenance of populations within areas of designated critical habitat (59 FR 13374).

### *5.1.2 Recovery factor criteria*

The recovery factor criteria are directly linked to management actions/tasks. Recovery factor criteria for downlisting generally call for identification, implementation, evaluation, and revision of management tasks. Corresponding criteria for delisting call for attainment of necessary and feasible levels of protection that minimize or remove threats. Reference to management actions and tasks in occupied habitat presupposes establishment of populations through augmentation.

Each of the four threats identified in section 4.0 (i.e., streamflow regulation, habitat modification, competition with and predation by nonnative fishes, and pesticides and pollutants) is addressed in this section with appropriate management actions/tasks. Details of these and other management actions/tasks that contribute to recovery are or will be identified in the RIPRAP of the UCRRP, Annual Work Plan of the SJRRIP, Adaptive Management Program Strategic Plan of the GCDAMP, and in annual work plans of the NFWG and MSCP. These programs function under the general principles of adaptive management, and the plans are periodically revised. In the context of these programs, adaptive management is the process by which management actions are identified, implemented, evaluated, and revised based on results of research and monitoring.

Providing and legally protecting habitat are necessary elements in recovery of the razorback sucker. Habitat as used in these recovery goals is defined as the physical and biological components of the environment required for recovery of the species, including flow regimes necessary to restore and maintain those environmental conditions. Hence, identification, implementation, evaluation, and revision of adequate flow regimes through adaptive management are identified as criteria necessary for downlisting. By the time of delisting, flows (as well other habitat components) identified as necessary to the life history of the species must be provided and legally protected through various means, including instream-flow appropriations, legal agreements, contracts, operating criteria, and/or other means. As stated in the governing documents of the UCRRP and the SJRRIP, under these programs legal protection of flows referenced in these recovery goals for upper basin rivers and the San Juan River will be consistent with State and Federal laws related to the Colorado River system (sometimes referred to as "Law of the River"), including State water law, interstate compacts, and Federal trust responsibilities to American Indian tribes. It is recognized that flow management alone is not sufficient to ensure self-sustaining populations of the endangered fishes, and that a combination of flow and non-flow management actions will be necessary for recovery. It is anticipated that flow management actions identified in these recovery goals can be achieved in balance with non-flow management actions to improve ecosystem conditions and enhance recovery and sustainability of the endangered fish populations. Population and demographic data collected through monitoring will be used to track progress toward meeting the habitat needs of the species.

Implementation of conservation plans is required in order to provide for the long-term management and protection of razorback sucker populations after delisting. These conservation plans will be developed and implemented through agreements among State agencies, Federal agencies, American Indian tribes, and other interested parties, and may include (but are not limited to) provision of flows for maintenance of habitat conditions required for all life stages, regulation and/or control of nonnative fishes, minimization of the risk of hazardous-materials spills, and monitoring of populations and habitats.

Use of hatchery fish (progeny of cultured broodstock) will be necessary to establish new populations or augment existing populations of razorback sucker. Provisions and recommendations of the Policy Regarding Controlled Propagation of Species Listed Under the Endangered Species Act (65 FR 56916) should be used as guidelines for use of hatchery fish in recovery. The UCRRP has a genetics management plan (Czapla 1999) and is revising a facilities-needs plan based on revised State stocking plans. Similar plans need to be developed for the SJRRIP and lower basin recovery unit.

### *5.1.3 Uncertainties*

These recovery goals are based on the best available scientific information, and are structured to attain a balance between reasonably achievable criteria and ensuring the viability of the species beyond delisting. Without wild viable populations, considerable uncertainty exists regarding recovery of the razorback sucker. It is expected that research, management, and monitoring activities directed by the UCRRP, SJRRIP, GCDAMP, NFWG, and MSCP will fill information gaps and considerably narrow, if not eliminate, many of the uncertainties that affect recovery criteria. As self-sustaining populations are established and studied, additional data and improved understanding of razorback sucker biology will prompt future revision of these recovery goals. The Service intends to review, and revise as needed, these recovery goals at least once every 5 years from the date of their publication in the *Federal Register*, or as necessary when sufficient new information warrants a change in the recovery criteria. Review of these recovery goals will be part of the review of listed species as required by Section 4(c)(2)(A) of the ESA, *"The Secretary shall ... conduct, at least once every five years, a review of all species..."*.
Uncertainties associated with these recovery goals include:

- Demographic Viability. The metapopulation concept may apply to razorback sucker populations, but the role of metapopulations in razorback sucker population dynamics can only be determined after populations become established.
- Carrying Capacity. The carrying capacity for razorback sucker populations is unknown. Numbers of fish in the wild are too few to make any inferences on carrying capacity.
- Genetic Viability. A conservative $N_e$ of 1,000 was used because of the absence of wild, self-sustaining populations to provide sorting of alleles to maintain natural genetic variability. Without wild populations, genetic viability is uncertain and not assured.
- Flow and Temperature Recommendations. Flow and temperature recommendations have been developed that specifically consider flow-habitat

relationships in habitats occupied by razorback sucker. However, it is uncertain to what extent these recommendations can be met and what flow regimes will be necessary to meet the life history needs of the razorback sucker. Streamflow reduction and modification from dams and water withdrawal systems have reduced spatial and temporal variability in flow regimes, reduced available habitat, and changed ecosystem function and structure. A paradigm in river management suggests that the ecological integrity of river ecosystems is linked to their natural dynamic character (Stanford et al. 1996; Poff et al. 1997), and restoring a more natural flow regime is the cornerstone of river restoration. This paradigm and the response by endangered fishes of the Colorado River Basin is largely untested, and as these flow regimes to benefit the endangered fishes are implemented, it is important to be aware of associated uncertainties and plan for management of unanticipated results. Response of razorback sucker to flows will need to be monitored in order to identify and provide flow regimes that are necessary to restore and maintain adequate habitat and sufficient range for all life stages.

- <u>Nonnative Fish Response</u>. Uncertainty exists regarding the responses of nonnative fishes to active control measures and to flow regimes to benefit the endangered fishes. Many of these nonnative fishes, both warm-water and cold-water, prey on and compete with native fishes. There are indications that high spring flows have a negative effect on nonnative fishes, but the overall response of nonnative fish populations to flow recommendations is uncertain. Long-term response by nonnative fishes to mechanical removal is also an uncertainty. It is unknown if reduction in numbers of nonnatives will result in lower population numbers, altered age structure, or opening of niches for new or existing nonnative fishes. It is also unknown if reduction in nonnative fishes will result in increased numbers of native fishes.
- <u>Efficacy of Monitoring Programs</u>. The precision and reliability of long-term monitoring programs to accurately measure the response of razorback sucker to management actions is an uncertainty. Mark-recapture estimates of established populations may reflect high variability because of population variability and/or sampling variability. This variability in estimates may exceed the level of population response to a management action, masking measurement of short-term responses and cause-effect relationships. Demographic criteria proposed in this document attempt to account for this variability and set numbers that are measurable under current conditions.
- <u>Establishing Self-Sustaining Populations</u>. Hatchery fish will be used to establish new populations or augment existing populations. The survival, recruitment, and reproductive success of these fish in the wild is uncertain. This uncertainty is greater in rivers or river reaches that have been extensively modified.
- <u>Response to Management Actions</u>. Response by razorback sucker populations to management actions is also uncertain. Management actions, such as repatriation of riverine habitats in the lower basin, regulation of escapement of nonnative fishes, control of parasites, control of nonnative fishes, and minimization of risk to hazardous-materials spills, may vary in their effectiveness to benefit razorback

sucker. Tasks and recovery criteria associated with each of these management actions are intended to provide some measure of success before reclassification can occur.

## 5.2 Site-Specific Management Actions and Tasks by Recovery Factor

### *5.2.1 Upper basin recovery unit*

#### 5.2.1.1 Factor A.—Adequate habitat and range for recovered populations provided

Management Action A-1.—Provide flows necessary for all life stages of razorback sucker to support recovered populations, based on demographic criteria.

Task A-1.1.—Identify, implement, evaluate, and revise (as necessary through adaptive management) flow regimes to benefit razorback sucker populations in the Green River, upper Colorado River, and San Juan River subbasins (see section 4.1 for discussion of existing flow recommendations to benefit the endangered fishes and for discussion of razorback sucker flow-habitat requirements; see Appendix A for a synopsis of razorback sucker life history).

Task A-1.2.—Provide flow regimes (as determined under Task A-1.1) that are necessary for all life stages of razorback sucker to support recovered populations in the Green River, upper Colorado River, and San Juan River subbasins.

Management Action A-2.—Provide passage for razorback sucker within occupied habitat to allow adequate movement and, potentially, range expansion.

Task A-2.1.—Continue to provide fish passage over Redlands Diversion and Grand Valley Diversion to allow adequate movement of razorback sucker in the upper Colorado River and Gunnison River (see section 4.1 for a discussion on barriers to fish passage).

Task A-2.2—Modify Price-Stubb Dam and Government Highline Dam to allow adequate movement of razorback sucker in the upper Colorado River.

Task A-2.3.—Identify, evaluate, and modify (as necessary) barriers on the San Juan River (e.g., Cudei Diversion, Hogback Diversion, and PNM Weir) to allow adequate movement of razorback sucker.

Management Action A-3.—Investigate options for providing appropriate water temperatures in the Gunnison River that would allow for range expansion of razorback sucker.

Task A-3.1.—Investigate the feasibility of modifying releases from Aspinall Unit dams to increase water temperatures in the Gunnison River that would allow for upstream range expansion of razorback sucker in the Gunnison River (see section 4.1 for discussion on warm-water releases).

Task A-3.2.—Modify releases from Aspinall Unit dams to increase water temperatures in the Gunnison River, if determined feasible and necessary to achieve demographic criteria for the upper Colorado River subbasin (see section 5.3.2.1.1).

Management Action A-4.—Minimize entrainment of subadult and adult razorback sucker in diversion canals.

Task A-4.1.—Identify measures (e.g., screens, baffles) to minimize entrainment of subadult and adult razorback sucker at problematic diversion structures, such as the Green River Canal, Grand Valley Irrigation Canal, Government Highline Diversion Project, and the Redlands Canal Company Diversion (see section 4.1 for discussion on entrainment).

Task A-4.2.—Install devices and/or implement other measures (as determined under Task A-4.1) to minimize entrainment.

Management Action A-5.—Provide floodplain habitats for all life stages of razorback sucker, particularly to serve as nursery areas for larvae and juveniles.

Task A-5.1.—Identify appropriate bottomland sites and assess opportunities for land acquisition or easements.

Task A-5.2.—Acquire or procure easements (as determined under Task A-5.1) for bottomland sites where determined necessary and feasible.

#### 5.2.1.2 Factor B.—Protection from overutilization for commercial, recreational, scientific, or educational purposes

Management Action B-1.—Protect razorback sucker populations from overutilization for commercial, recreational, scientific, or educational purposes.

Task B-1.1.—Reevaluate and, if necessary, identify actions to ensure adequate protection from overutilization of razorback sucker for commercial, recreational, scientific, or educational purposes; not currently identified as an existing threat (see section 4.2).

Task B-1.2.—Implement identified actions (as determined under Task B-1.1) to ensure adequate protection of razorback sucker populations from overutilization for commercial, recreational, scientific, or educational purposes.

**5.2.1.3 Factor C.—Adequate protection from diseases and predation**

Management Action C-1.—Minimize adverse effects of diseases and parasites on razorback sucker populations.

Task C-1.1.—Reevaluate and, if necessary, identify actions to minimize adverse effects of diseases and parasites on razorback sucker populations; not currently identified as an existing threat (see sections 4.3.1 and A.12 for discussion of diseases and parasites).

Task C-1.2.—Implement identified actions (as determined under Task C-1.1) to ensure adequate protection of razorback sucker populations from deleterious diseases and parasites.

Management Action C-2.—Regulate nonnative fish releases and escapement into the main river, floodplain, and tributaries.

Task C-2.1.—Develop, implement, evaluate, and revise (as necessary through adaptive management) procedures for stocking nonnative fish species in the Upper Colorado River Basin (including the San Juan River subbasin) to minimize negative interactions between nonnative fishes and razorback sucker (see sections 4.3.2 and A.8 for discussion of effects of nonnative fishes).

Task C-2.2.—Finalize and implement procedures (as determined under Task C-2.1) for stocking nonnative fish species in the Upper Colorado River Basin to minimize negative interactions between nonnative fishes and razorback sucker.

` Management Action C-3.—Control problematic nonnative fishes as needed.

Task C-3.1.—Develop control programs for small-bodied nonnative fishes (e.g., cyprinids and centrarchids) in backwater and flooded off-channel nursery habitats in river reaches occupied by young razorback sucker to identify the levels of control that will minimize predation (see sections 4.3.2 and A.8 for discussion of effects of nonnative fishes).

Task C-3.2.—Implement identified levels (as determined under Task C-3.1) of nonnative fish control in backwater and flooded off-channel nursery habitats in river reaches occupied by young razorback sucker.

Task C-3.3.—Develop channel catfish control programs in river reaches occupied by razorback sucker to identify levels of control that will minimize predation.

Task C-3.4.—Implement identified levels (as determined under Task C-3.3) of channel catfish control in river reaches occupied by razorback sucker.

Task C-3.5.—Develop northern pike control programs in reaches of the middle Green River occupied by razorback sucker to identify levels of control that will minimize predation.

Task C-3.6.—Implement identified levels (as determined under Task C-3.5) of northern pike control in reaches of the middle Green River occupied by razorback sucker.

#### 5.2.1.4 Factor D.—Adequate existing regulatory mechanisms

Management Action D-1.—Legally protect habitat (see definition of habitat in section 5.1.2) necessary to provide adequate habitat and sufficient range for all life stages of razorback sucker to support recovered populations, based on demographic criteria.

Task D-1.1.—Determine the mechanisms for legal protection of adequate habitat through instream-flow rights, contracts, agreements, or other means (see section 4.4 for discussion of regulatory mechanisms).

Task D-1.2.—Implement mechanisms for legal protection of habitat (as determined under Task D-1.1) that are necessary to restore and maintain adequate habitat and sufficient range for all life stages of razorback sucker to support recovered populations.

Management Action D-2.—Provide for the long-term management and protection of razorback sucker populations and their habitats.

Task D-2.1.—Identify elements needed for the development of conservation plans that are necessary to provide for the long-term management and protection of razorback sucker populations; elements of these plans may include (but are not limited to) provision of flows for maintenance of adequate habitat conditions for all life stages of razorback sucker, regulation and/or control of nonnative fishes, minimization of the risk of hazardous-materials spills, and monitoring of populations and habitats (see section 4.4 for discussion of need for conservation plans).

Task D-2.2.—Develop and implement conservation plans and execute agreements among State agencies, Federal agencies, American Indian tribes, and other interested parties to provide reasonable assurances that conditions needed for recovered razorback sucker populations will be maintained.

### 5.2.1.5 Factor E.—Other natural or manmade factors for which protection has been provided

Management Action E-1.—Minimize the threat of hybridization with white sucker in river reaches occupied by razorback sucker.

> Task E-1.1.—Reevaluate levels of hybridization with white sucker, assess effects on razorback sucker populations, and, if necessary, develop white sucker control programs in river reaches occupied by razorback sucker to identify levels of control that will minimize hybridization; not currently identified as an existing threat (see sections 4.5.1 and A.3 for discussion of hybridization).

> Task E-1.2.—Implement identified levels (as determined under Task E-1.1) of white sucker control in river reaches occupied by razorback sucker.

Management Action E-2.—Minimize the risk of hazardous-materials spills in critical habitat.

> Task E-2.1.—Review and recommend modifications to State and Federal hazardous-materials spills emergency-response plans to ensure adequate protection for razorback sucker populations from hazardous-materials spills, including prevention and quick response to hazardous-materials spills (see section 4.5.2 for discussion of hazardous-materials spills).

> Task E-2.2.—Implement State and Federal emergency-response plans that contain the necessary preventive measures (as determined under Task E-2.1) for hazardous-materials spills.

> Task E-2.3.—Identify the locations of all petroleum-product pipelines within the 100-year floodplain of critical habitat and assess the need for emergency shut-off valves to minimize the potential for spills.

> Task E-2.4.—Install emergency shut-off valves (as determined under Task E-2.3) on problematic petroleum-product pipelines within the 100-year floodplain of critical habitat.

Management Action E-3.—Minimize the threats from degraded water quality on razorback sucker.

> Task E-3.1.— Identify actions to remediate groundwater contamination from the Atlas Mills tailings pile located near Moab, Utah, in order to restore water quality of the Colorado River in the vicinity of the pile in accordance with the State of Utah and Environmental Protection Agency (EPA) water-quality standards for fish and wildlife (see section 4.5.2 for discussion of groundwater contamination).

Task E-3.2.— Implement actions (as determined under Task E-3.1) to remediate groundwater contamination from the Atlas Mills tailings pile.

Management Action E-4.—Minimize adverse effects of selenium contamination on razorback sucker reproductive success and survival of young and reduce deleterious levels of selenium contamination, if necessary.

Task E-4.1.—Reevaluate the effects of selenium contamination on razorback sucker reproductive success and survival of young, and, if necessary, identify actions to reduce deleterious levels of selenium contamination (see section 4.5.2 for discussion of selenium effects).

Task E-4.2.—Implement identified actions (as determined under Task E-4.1) to reduce deleterious levels of selenium contamination.

### *5.2.2 Lower basin recovery unit*

#### 5.2.2.1 Factor A.—Adequate habitat and range for recovered populations provided

Management Action A-1.—Provide flows necessary for all life stages of razorback sucker to support recovered populations, based on demographic criteria.

Task A-1.1.—Identify, implement, evaluate, and revise (as necessary through adaptive management) flow regimes that are necessary for the establishment and maintenance of razorback sucker populations in the mainstem and/or tributaries.

Task A-1.2.—Provide flow regimes (as determined under Task A-1.1) that are necessary for all life stages of razorback sucker to support recovered populations in the mainstem and/or tributaries.

Management Action A-2.—Minimize entrainment of subadult and adult razorback sucker in diversion and/or out-take structures.

Task A-2.1.—Identify measures (e.g., screens, baffles) to minimize entrainment of subadult and adult razorback sucker at problematic diversion and/or out-take structures (see section 4.1 for discussion on entrainment).

Task A-2.2.—Install devices and/or implement other measures (as determined under Task A-2.1) to minimize entrainment.

Management Action A-3.—Provide riverside habitats (e.g., oxbows, depressions, and bottomlands) for all life stages of razorback sucker.

Task A-3.1.—Identify appropriate riverside sites and assess opportunities for land acquisition or easements.

Task A-3.2.—Acquire or procure easements (as determined under Task A-3.1) for riverside sites where determined necessary and feasible.

#### 5.2.2.2 Factor B.—Protection from overutilization for commercial, recreational, scientific, or educational purposes

Management Action B-1.—Protect razorback sucker populations from overutilization for commercial, recreational, scientific, or educational purposes.

Task B-1.1.—Reevaluate and, if necessary, identify actions to ensure adequate protection from overutilization of razorback sucker for commercial, recreational, scientific, or educational purposes; not currently identified as an existing threat (see section 4.2).

Task B-1.2.—Implement identified actions (as determined under Task B-1.1) to ensure adequate protection of razorback sucker from overutilization for commercial, recreational, scientific, or educational purposes.

#### 5.2.2.3 Factor C.—Adequate protection from diseases and predation

Management Action C-1.—Minimize adverse effects of diseases and parasites on razorback sucker populations.

Task C-1.1.—Reevaluate and, if necessary, identify actions to minimize adverse effects of diseases and parasites on razorback sucker populations; not currently identified as an existing threat (see sections 4.3.1 and A.12 for discussion of diseases and parasites).

Task C-1.2.—Implement identified actions (as determined under Task C-1.1) to ensure adequate protection of razorback sucker populations from deleterious diseases and parasites.

Management Action C-2.—Regulate nonnative fish releases and escapement into the mainstem, floodplain, and tributaries.

Task C-2.1.—Develop, implement, evaluate, and revise (as necessary through adaptive management) procedures for stocking and to minimize escapement of nonnative fish species into the mainstem, floodplain, and tributaries to minimize negative interactions between nonnative fishes and razorback sucker (see sections 4.3.2 and A.8 for discussion of effects of nonnative fishes).

Task C-2.2.—Finalize and implement procedures (as determined under Task C-2.1) for stocking and to minimize escapement of nonnative fish species into the mainstem, floodplain, and tributaries to minimize negative interactions between nonnative fishes and razorback sucker.

Management Action C-3.—Control problematic nonnative fishes as needed.

Task C-3.1.—Develop control programs for problematic nonnative fishes in the mainstem, floodplain, and tributaries to identify levels of control that will minimize negative interactions between nonnative fishes and razorback sucker.

Task C-3.2.—Implement the identified levels (as determined under Task C-3.1) of nonnative fish control in the mainstem, floodplain, and tributaries.

#### 5.2.2.4 Factor D.—Adequate existing regulatory mechanisms

Management Action D-1.—Legally protect habitat (see definition of habitat in section 5.1.2) necessary to provide adequate habitat and sufficient range for all life stages of razorback sucker to support recovered populations, based on demographic criteria.

Task D-1.1.—Determine mechanisms for legal protection of adequate habitat through instream-flow rights, contracts, agreements, or other means (see section 4.4 for discussion of regulatory mechanisms).

Task D-1.2.—Implement mechanisms for legal protection of habitat (as determined under Task D-1.1) that are necessary to provide adequate habitat and sufficient range for all life stages of razorback sucker to support recovered populations.

Management Action D-2.—Provide for the long-term management and protection of razorback sucker populations and their habitats.

Task D-2.1.—Identify elements needed for the development of conservation plans that are necessary to provide for the long-term management and protection of razorback sucker populations; elements of these plans may include (but are not limited to) maintenance of genetic diversity in Lake Mohave, provision of flows for maintenance of adequate habitat conditions for all life stages of razorback sucker, regulation and/or control of nonnative fishes, and monitoring of populations and habitats (see section 4.4 for discussion of need for conservation plans).

Task D-2.2.—Develop and implement conservation plans and execute agreements among State agencies, Federal agencies, American Indian tribes, and other interested parties to provide reasonable assurances that conditions needed for recovered razorback sucker populations will be maintained.

#### 5.2.2.5 Factor E.—Other natural or manmade factors for which protection has been provided

No other factors have been identified as threats.

## 5.3 Objective, Measurable Recovery Criteria

### *5.3.1 Downlist criteria*

#### 5.3.1.1 Demographic criteria for downlisting (population demographics in both recovery units must be met in order to achieve downlisting)

##### 5.3.1.1.1 Upper basin recovery unit

**Green River Subbasin**

1. A self-sustaining population is maintained over a 5-year period, starting with the first point estimate acceptable to the Service, such that:

   a. the trend in adult (age 4+; $\geq$400 mm TL) point estimates does not decline significantly, and

   b. mean estimated recruitment of age-3 (300–399 mm TL) naturally produced fish equals or exceeds mean annual adult mortality, and

   c. each population point estimate exceeds 5,800 adults (Note: 5,800 is the estimated MVP number; see section 3.3.2).

**Upper Colorado River and San Juan River Subbasins**

2. A self-sustaining population is maintained in **EITHER** the upper Colorado River subbasin or the San Juan River subbasin over a 5-year period, starting with the first point estimate acceptable to the Service, such that for either population:

   a. the trend in adult (age 4+; $\geq$400 mm TL) point estimates does not decline significantly, and

   b. mean estimated recruitment of age-3 (300–399 mm TL) naturally produced fish equals or exceeds mean annual adult mortality, and

   c. each point estimate exceeds 5,800 adults (MVP).

##### 5.3.1.1.2 Lower basin recovery unit

1. Genetic variability of razorback sucker in Lake Mohave is identified, and a genetic refuge is maintained over a 5-year period.

2. Two self-sustaining populations (e.g., mainstem and/or tributaries) are maintained over a 5-year period, starting with the first point estimate acceptable to the Service, such that for each population:

   a. the trend in adult (age 4+; ≥400 mm TL) point estimates does not decline significantly, and

   b. mean estimated recruitment of age-3 (300–399 mm TL) naturally produced fish equals or exceeds mean annual adult mortality, and

   c. each point estimate exceeds 5,800 adults (MVP).

**5.3.1.2 Recovery factor criteria for downlisting (population demographics in both recovery units must be met in order to achieve downlisting)**

**5.3.1.2.1 Upper basin recovery unit**

**Factor A.—Adequate habitat and range for recovered populations provided.**

1. Flow regimes to benefit razorback sucker populations in the Green River, upper Colorado River, and San Juan River subbasins identified, implemented, evaluated, and revised (Task A-1.1), such that:

   a. Adequate spawning habitat and appropriate spawning cues (e.g., flow patterns and water temperatures) are available to maintain self-sustaining populations, as reflected by downlisting demographic criteria in section 5.3.1.1.1.

   b. Adequate nursery habitat is available to maintain self-sustaining populations, as reflected by downlisting demographic criteria in section 5.3.1.1.1.

   c. Adequate juvenile and adult habitat (e.g., cover, resting, and feeding areas) are available to maintain self-sustaining populations, as reflected by downlisting demographic criteria in section 5.3.1.1.1.

2. Passage over Redlands Diversion and Grand Valley Diversion continued to allow adequate movement of razorback sucker in the upper Colorado River and Gunnison River (Task A-2.1).

3. Modification of Price-Stubb Dam and Government Highline Dam initiated to allow adequate movement of razorback sucker in the upper Colorado River (Task A-2.2).

4. Barriers on the San Juan River identified and evaluated, and modifications initiated to allow adequate movement of razorback sucker (Task A-2.3).

5. Investigations initiated on the feasibility of modifying releases from Aspinall Unit dams to increase water temperatures in the Gunnison River that would allow for upstream range expansion of razorback sucker (Task A-3.1).

6. Measures identified to minimize entrainment of subadult and adult razorback sucker at problematic diversion structures (Task A-4.1).

7. Appropriate bottomland sites identified and opportunities for land acquisition or easements assessed (Task A-5.1).

**Factor B.—Protection from overutilization for commercial, recreational, scientific, or educational purposes.**

8. Overutilization of razorback sucker for commercial, recreational, scientific, or educational purposes reevaluated and, if necessary, actions identified to ensure adequate protection (Task B-1.1).

**Factor C.—Adequate protection from diseases and predation.**

9. Effects of diseases and parasites on razorback sucker populations reevaluated and, if necessary, actions identified to ensure adequate protection (Task C-1.1).

10. Procedures developed, implemented, evaluated, and revised for stocking nonnative fish species in the Upper Colorado River Basin (including the San Juan River subbasin) to minimize negative interactions between nonnative fishes and razorback sucker (Task C-2.1).

11. Control programs for small-bodied nonnative fishes in backwater and flooded off-channel nursery habitats in river reaches occupied by young razorback sucker developed and implemented to identify levels of control that will minimize predation (Task C-3.1).

12. Channel catfish control programs in river reaches occupied by razorback sucker developed and implemented to identify levels of control that will minimize predation (Task C-3.3).

13. Northern pike control program in reaches of the middle Green River occupied by razorback sucker developed and implemented to identify levels of control that will minimize predation (Task C-3.5).

**Factor D.—Adequate existing regulatory mechanisms.**

14. Mechanisms determined for legal protection of adequate habitat (Task D-1.1).

15. Elements of conservation plans identified that are necessary to provide for the long-term management and protection of razorback sucker populations (Task D-2.1).

**Factor E.—Other natural or manmade factors for which protection has been provided.**

16. Levels of hybridization with white sucker reevaluated, effects on razorback sucker populations assessed, and, if necessary, white sucker control programs in river reaches occupied by razorback sucker developed and implemented to identify levels of control that will minimize hybridization (Task E-1.1)

17. State and Federal hazardous-materials spills emergency-response plans reviewed and modified to ensure adequate protection for razorback sucker populations from hazardous-materials spills (Task E-2.1).

18. Locations of all petroleum-product pipelines within the 100-year floodplain of critical habitat identified and the need for emergency shut-off valves assessed (Task E-2.3).

19. Actions identified for remediation of groundwater contamination at the Atlas Mills tailings pile located near Moab, Utah (Task E-3.1).

20. Effects of selenium contamination on razorback sucker reproductive success and survival of young reevaluated, and, if necessary, actions identified to reduce deleterious levels of selenium contamination (Task E-4.1).

**5.3.1.2.2 Lower basin recovery unit**

**Factor A.—Adequate habitat and range for recovered populations provided.**

1. Flow regimes that are necessary for establishment and maintenance of razorback sucker populations in the mainstem and/or tributaries identified, implemented, evaluated, and revised (Task A-1.1), such that:

    a. Adequate spawning habitat and appropriate spawning cues (e.g., flow patterns and water temperatures) are available to maintain self-sustaining populations, as reflected by downlisting demographic criteria in section 5.3.1.1.2.

b. Adequate nursery habitat is available to maintain self-sustaining populations, as reflected by downlisting demographic criteria in section 5.3.1.1.2.

c. Adequate juvenile and adult habitat (e.g., cover, resting, and feeding areas) are available to maintain self-sustaining populations, as reflected by downlisting demographic criteria in section 5.3.1.1.2.

2. Measures identified to minimize entrainment of subadult and adult razorback sucker at problematic diversion and/or out-take structures (Task A-2.1).

3. Appropriate riverside sites identified and opportunities for land acquisition or easements assessed (Task A-3.1).

**Factor B.—Protection from overutilization for commercial, recreational, scientific, or educational purposes.**

4. Overutilization of razorback sucker for commercial, recreational, scientific, or educational purposes reevaluated and, if necessary, actions identified to ensure adequate protection (Task B-1.1).

**Factor C.—Adequate protection from diseases and predation.**

5. Effects of diseases and parasites on razorback sucker populations reevaluated and, if necessary, actions identified to ensure adequate protection (Task C-1.1).

6. Procedures developed, implemented, evaluated, and revised for stocking and to minimize escapement of nonnative fish species into the mainstem, floodplain, and tributaries to minimize negative interactions between nonnative fishes and razorback sucker (Task C-2.1).

7. Control programs for problematic nonnative fishes in the mainstem, floodplain, and tributaries developed and implemented to identify levels of control that will minimize negative interactions between nonnative fishes and razorback sucker (Task C-3.1).

**Factor D.—Adequate existing regulatory mechanisms.**

8. Mechanisms determined for legal protection of adequate habitat (Task D-1.1).

9. Elements of conservation plans identified that are necessary to provide for the long-term management and protection of razorback sucker populations (Task D-2.1).

**Factor E.—Other natural or manmade factors for which protection has been provided.**

No other factors have been identified as threats.

### *5.3.2 Delist criteria*

#### 5.3.2.1 Demographic criteria for delisting (population demographics in both recovery units must be met in order to achieve delisting)

##### 5.3.2.1.1 Upper basin recovery unit

**Green River Subbasin**

1. A self-sustaining population is maintained over a 3-year period beyond downlisting, starting with the first point estimate acceptable to the Service, such that:

   a. the trend in adult (age 4+; ≥400 mm TL) point estimates does not decline significantly, and

   b. mean estimated recruitment of age-3 (300–399 mm TL) naturally produced fish equals or exceeds mean annual adult mortality, and

   c. each population point estimate exceeds 5,800 adults (MVP).

**Upper Colorado River and San Juan River Subbasins**

2. A self-sustaining population is maintained over a 3-year period beyond downlisting, starting with the first point estimate acceptable to the Service, in **EITHER** the upper Colorado River subbasin or the San Juan River subbasin, such that:

   a. the trend in adult (age 4+; ≥400 mm TL) point estimates does not decline significantly, and

b. mean estimated recruitment of age-3 (300–399 mm TL) naturally produced fish equals or exceeds mean annual adult mortality, and

c. each point estimate exceeds 5,800 adults (MVP).

**5.3.2.1.2 Lower basin recovery unit**

1. A genetic refuge is maintained in Lake Mohave over a 3-year period beyond downlisting.

2. Two self-sustaining populations (e.g., mainstem and/or tributaries) are maintained over a 3-year period beyond downlisting, starting with the first point estimate acceptable to the Service, such that for each population:

   a. the trend in adult (age 4+; ≥400 mm TL) point estimates does not decline significantly, and

   b. mean estimated recruitment of age-3 (300–399 mm TL) naturally produced fish equals or exceeds mean annual adult mortality, and

   c. each point estimate exceeds 5,800 adults (MVP).

**5.3.2.2 Recovery factor criteria for delisting (recovery factor criteria in both recovery units must be met in order to achieve delisting)**

**5.3.2.2.1 Upper basin recovery unit**

**Factor A.—Adequate habitat and range for recovered populations provided.**

1. Flow regimes provided that are necessary for all life stages of razorback sucker to support recovered populations in the Green River, upper Colorado River, and San Juan River subbasins (Task A-1.2), such that:

   a. Adequate spawning habitat and appropriate spawning cues (e.g., flow patterns and water temperatures) are available to maintain self-sustaining populations, as reflected by delisting demographic criteria in section 5.3.2.1.1.

   b. Adequate nursery habitat are available to maintain self-sustaining populations, as reflected by delisting demographic criteria in section 5.3.2.1.1.

   c. Adequate juvenile and adult habitat (e.g., cover, resting, and feeding areas) are available to maintain self-sustaining populations, as reflected by delisting demographic criteria in section 5.3.2.1.1.

2. Passage over Redlands Diversion and Grand Valley Diversion continued to allow adequate movement of razorback sucker in the upper Colorado River and Gunnison River (Task A-2.1).

3. Modification of Price-Stubb Dam and Government Highline Dam completed to allow adequate movement of razorback sucker in the upper Colorado River (Task A-2.2).

4. Barriers on the San Juan River modified to allow adequate movement of razorback sucker (Task A-2.3).

5. Releases from Aspinall Unit dams to increase water temperatures in the Gunnison River are modified, if detemined feasible and necessary to achieve demographic criteria for the upper Colorado River subbasin (see section 5.3.2.1.1) to allow for upstream range expansion of razorback sucker (Task A-3.2).

6. Devices installed and/or measures implemented at problematic diversion structures to minimize entrainment of subadult and adult razorback sucker (Task A-4.2).

7. Bottomland sites acquired or easements procured (Task A-5.2).

**Factor B.—Protection from overutilization for commercial, recreational, scientific, or educational purposes.**

8. Adequate protection of razorback sucker populations from overutilization for commercial, recreational, scientific, or educational purposes attained (Task B-1.2).

**Factor C.—Adequate protection from diseases and predation.**

9. Adequate protection of razorback sucker populations from deleterious diseases and parasites attained (Task C-1.2).

10. Procedures finalized and implemented for stocking nonnative fish species in the Upper Colorado River Basin to minimize negative interactions between nonnative fishes and razorback sucker (Task C-2.2).

11. Identified levels of nonnative fish control to minimize predation attained in backwater and flooded off-channel nursery habitats in river reaches occupied by young razorback sucker (Task C-3.2).

12. Identified levels of channel catfish control to minimize predation attained in river reaches occupied by razorback sucker (Task C-3.4).

13. Identified levels of northern pike control to minimize predation attained in reaches of the middle Green River occupied by razorback sucker (Task C-3.6).

**Factor D.—Adequate existing regulatory mechanisms.**

14. Habitat necessary to provide adequate habitat and sufficient range for all life stages of razorback sucker to support recovered populations in the Green River, upper Colorado River, and San Juan River subbasins is legally protected in perpetuity (Tasks D-1.2).

15. Conservation plans developed and implemented, and agreements among State agencies, Federal agencies, American Indian tribes, and other interested parties executed to provide reasonable assurances that conditions needed for recovered razorback sucker populations will be maintained (Task D-2.2).

**Factor E.—Other natural or manmade factors for which protection has been provided.**

16. Identified levels of white sucker control to minimize hybridization attained in river reaches occupied by razorback sucker (Task E-1.2).

17. State and Federal emergency-response plans implemented that contain the necessary preventive measures for hazardous-materials spills (Task E-2.2).

18. Emergency shut-off valves installed on all problematic petroleum-product pipelines within the 100-year floodplain of critical habitat (Task E-2.4).

19. Groundwater contamination remediated at the Atlas Mills tailings pile located near Moab, Utah, and water quality of the Colorado River in the vicinity of the pile restored in compliance with the State of Utah and EPA water-quality standards for fish and wildlife (Task E-3.2).

20. Deleterious levels of selenium contamination reduced to minimize adverse effects on razorback sucker reproductive success and survival of young (Task E-4.2).

#### 5.2.2.2.2 Lower basin recovery unit

**Factor A.—Adequate habitat and range for recovered populations provided.**

1. Flow regimes provided that are necessary for all life stages of razorback sucker to support recovered populations in the mainstem, floodplain, and tributaries (Task A-1.2), such that:

   a. Adequate spawning habitat and appropriate spawning cues (e.g., flow patterns and water temperatures) are available to maintain self-sustaining populations, as reflected by delisting demographic criteria in section 5.3.2.1.2.

   b. Adequate nursery habitat is available to maintain self-sustaining populations, as reflected by delisting demographic criteria in section 5.3.2.1.2.

   c. Adequate juvenile and adult habitat (e.g., cover, resting, and feeding areas) is available to maintain self-sustaining populations, as reflected by delisting demographic criteria in section 5.3.2.1.2.

2. Devices installed and/or measures implemented at problematic diversion and/or out-take structures to minimize entrainment of subadult and adult razorback sucker (Task A-2.2).

3. Riverside sites acquired or easements procured (Task A-3.2).

**Factor B.—Protection from overutilization for commercial, recreational, scientific, or educational purposes.**

4. Adequate protection of razorback sucker from overutilization for commercial, recreational, scientific, or educational purposes attained (Task B-1.2).

**Factor C.—Adequate protection from diseases and predation.**

5. Adequate protection of razorback sucker populations from deleterious diseases and parasites attained (Task C-1.2).

6. Procedures finalized and implemented for stocking nonnative fish species in the mainstem, floodplain, and tributaries to minimize negative interactions between nonnative fishes and razorback sucker (Task C-2.2).

7. Identified levels of nonnative fish control to minimize negative interactions between nonnative fishes and razorback sucker attained in the mainstem, floodplain, and tributaries (Task C-3.2).

**Factor D.—Adequate existing regulatory mechanisms.**

8. Habitat necessary to provide adequate habitat and sufficient range for all life stages of razorback sucker to support recovered populations is legally protected in perpetuity (Task D-1.2).

9. Conservation plans developed and implemented, and agreements among State agencies, Federal agencies, American Indian tribes, and other interested parties executed to provide reasonable assurances that conditions needed for recovered razorback sucker populations will be maintained (Task D-2.2).

**Factor E.—Other natural or manmade factors for which protection has been provided.**

No other factors have been identified as threats.

## 5.4 Estimated Time To Achieve Recovery of the Razorback Sucker

Extant populations of razorback sucker are small with little or no recruitment. Therefore, use of hatchery fish (progeny of cultured brood stock) will be necessary to establish new populations or augment existing populations. Time to achieve recovery of the razorback sucker cannot be accurately estimated until self-sustaining populations are established through augmentation and habitat enhancement. The rate at which populations become established will depend on survival of stocked fish in the wild, integration of stocked fish with wild stocks, reproductive success, and recruitment. Response of the species to ongoing management activities will need to be assessed through monitoring, and strategies for recovery and estimates of time to achieve recovery will be reevaluated periodically. Based on current information and associated uncertainties, it is estimated that self-sustaining populations of razorback sucker will become established over the next 15 years. During this time, population dynamics and responses to management actions will be evaluated.

For razorback sucker populations to be self-sustaining, adults must reproduce and recruitment of young fish into the adult population must occur at a rate to maintain the population at a minimum of 5,800 adults. When this occurs, the definition of a "self-sustaining" population is met, and the "clock" starts on the downlisting and delisting process.

Once self-sustaining populations have been established, estimated time to achieve recovery of the bonytail is 5 years for downlisting and an additional 3 years for delisting. Self-sustaining populations and first reliable point estimates for all populations are expected by 2015. If those estimates are acceptable to the Service and all recovery criteria are met, downlisting could be proposed in 2020 and delisting could be proposed in 2023 (Figure 2).

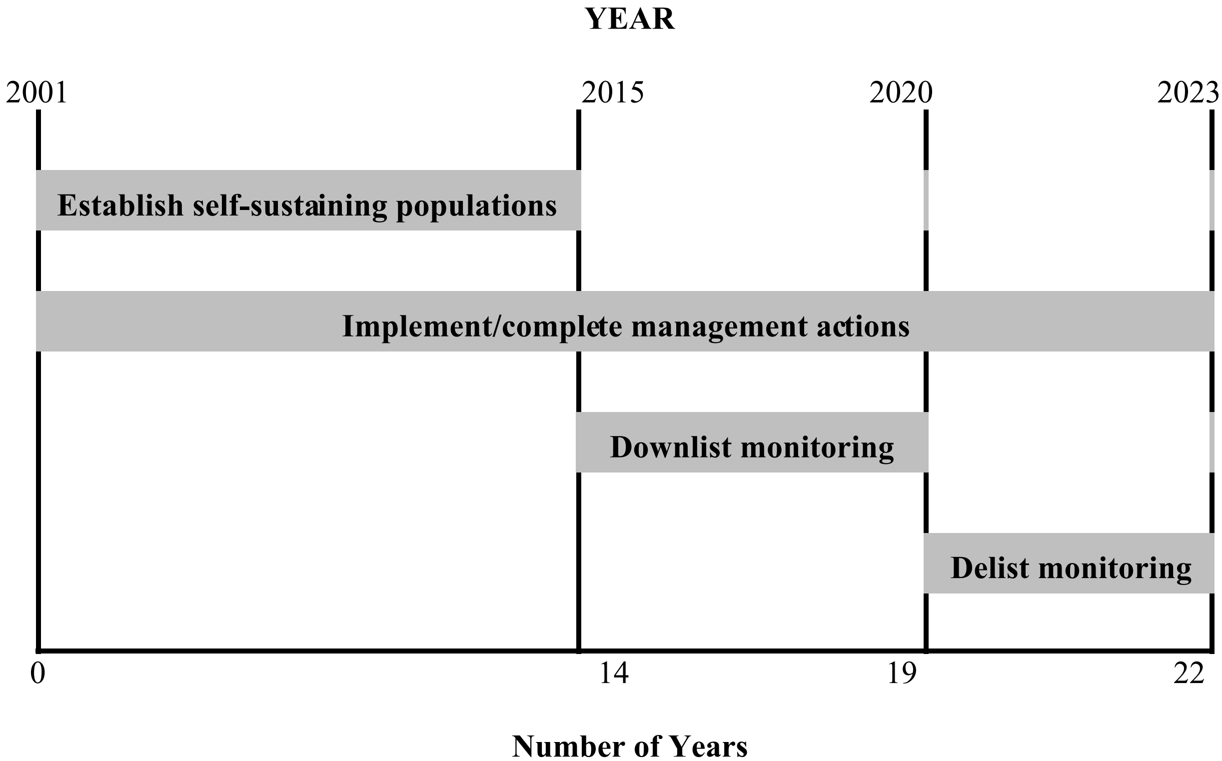


Figure 2. Estimated time to achieve recovery of the razorback sucker.

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# APPENDIX A.

## LIFE HISTORY OF THE RAZORBACK SUCKER

Following is a synopsis of razorback sucker life history. This assimilation of information represents an overview of the best scientific information available for the species at this time. A more detailed description of life history and historic distribution was presented by Minckley et al. (1991). Additional and more detailed information can be found in literature cited in this document and in reports and publications referenced in those citations.

### A.1 Species Description

The razorback sucker is the only species of the genus *Xyrauchen*, one of four genera in the tribe Catostomini of the family of suckers, Catostomidae. The species was described in 1860 as *Catostomus texanus* by Abbott (1861), and redescribed later as *Xyrauchen texanus* (Kirsch 1889; Jordan and Evermann 1896; LaRivers 1962). The razorback sucker is a robust, river catostomid with maximum size of about 1 m total length (TL) and 5–6 kg (Minckley 1973), although adults are typically 400–700 mm TL and weigh less than 3 kg (McCarthy and Minckley 1987). Females appear to reach larger sizes than males and have relatively smaller fins (Minckley 1983; Tyus and Karp 1990; Minckley et al. 1991), whereas males develop stronger, more dense nuptial tubercles on surfaces of the anal and caudal fins, caudal peduncle, and postero-lateral body (Minckley et al. 1991). Adults are elongated and slightly compressed laterally, with a bony, sharp-edged dorsal keel immediately posterior to the occiput. For many years, this species was commonly known as the "humpback sucker" because of this keel. The keel is formed by the growth and fusion of three interneural bones located just behind the head. The shape and size of the interneural bones is diagnostic for several species of suckers (Snyder and Muth 1990). The appearance of the keel varies with size and age of fish and may be evident on individuals as small as 100 mm TL, although it is usually not distinct until fish are about 200 mm TL. The head is elongated with a flattened dorsal surface, and the mouth is prominent and located ventrally. There are usually 14–15 principal rays in the dorsal fin and 7 in the anal fin. The scales are well developed with 68–87 in the lateral line. In adults, the upper body is dark brown to olivaceous, with the lower ventro-lateral surfaces ranging from white to yellow (Minckley 1973). A variously developed lateral band can be yellowish, orange, reddish to reddish brown or even violet (Minckley et al. 1991). Breeding males exhibit very dark, even black, dorsal surfaces and bright yellow to orange ventro-lateral surfaces (Sigler and Miller 1963). Razorback sucker are reported to hybridize with native flannelmouth sucker (*Catostomus latipinnis*) and bluehead sucker (*C. discobolus*; Hubbs and Miller 1953), and possibly with nonnative white sucker (*C. commersoni*; McAda and Wydoski 1980).

### A.2 Distribution and Abundance

Historically, the razorback sucker occupied the mainstem Colorado River and many of its tributaries from northern Mexico through Arizona and Utah into Wyoming, Colorado, and New Mexico. In the late 19$^{th}$ and early 20$^{th}$ centuries, it was reported as being abundant in the Lower

Colorado River Basin and common in parts of the Upper Colorado River Basin, with numbers apparently declining with distance upstream (Jordan and Evermann 1896; Minckley et al. 1991).

In the lower basin, razorback sucker were found in abundance in the lower Colorado River from the delta in Mexico north to what is now Lake Mohave in Arizona, and in the Gila, San Pedro, Verde, and Salt rivers (Miller 1961; Minckley 1983; Minckley et al. 1991). Early accounts place these fish in the Gila River from its confluence with the Colorado River (Evermann and Rutter 1895) almost to the Arizona-New Mexico border (Minckley 1973), and in the San Pedro River as far south as Tombstone, Arizona. Archaeological remains document occurrence in the Verde River as far upstream as Perkinsville, Arizona (Miller 1961). Razorback sucker were so numerous in the Salt River above Lake Roosevelt, in Saguaro Lake, and in irrigation canals near Phoenix, Arizona, that they were removed by the wagon load and sold commercially for food and fertilizer (Minckley 1983). Large numbers were also taken from the Salton Sea of southern California (Evermann 1916).

Although razorback sucker occupied the mainstem Colorado River in the reach now inundated by Lake Mead and in Grand Canyon, few records exist, possibly because these regions were relatively remote and inaccessible for sampling (Minckley et al. 1991). Only 10 razorback sucker were documented from Grand Canyon between 1944 and 1995 (Valdez 1996), and the species is considered to be transient through this region to reach more suitable habitats upstream and downstream (Bestgen 1990; Douglas and Marsh 1998). A number of hybrids between flannelmouth sucker and razorback sucker are reported from Grand Canyon (Suttkus et al. 1976; Maddux et al. 1987; Valdez and Ryel 1995; Douglas and Marsh 1998).

Historic distribution of razorback sucker in the upper basin included the Colorado, Green, and San Juan River drainages (Minckley et al. 1991; Holden 1999; Muth et al. 2000). Evidence suggests that the species was common and possibly locally abundant in the lower, flat-water reaches of the Green and Colorado rivers and in the lower reaches of some tributaries (Minckley et al. 1991; Muth et al. 2000). This species was reported from the White, Duchesne, Little Snake, Yampa, and Gunnison rivers (Burdick 1995), and, although evidence is sparse and anecdotal, as far up the San Juan River drainage as the Animas River (Jordan 1891; Minckley et al. 1991; U.S. Fish and Wildlife Service 1998).

Distribution and abundance of razorback sucker declined throughout the 20th century over all of its historic range, and the species now exists naturally only in a few small, discontiguous populations or as dispersed individuals. These fish have exhibited little natural recruitment in the last 40–50 years, and wild populations are composed primarily of aging adults, with steep declines in numbers. Reproduction occurs, but very few juveniles are found. In the lower basin, this species was extirpated from the Salton Sea by the late 1920's and from the Gila River drainage by the late 1960's (Minckley et al. 1991; Muth et al. 2000). Razorback sucker have persisted in the lower mainstem Colorado River, concentrating in Lakes Mohave and Mead (Minckley 1983). Few and decreasing numbers of wild fish have also been caught in Lake Havasu, at several other locations along the river, and in water diversion facilities (Bozek et al. 1991; Minckley et al. 1991).

Currently, the group of razorback sucker in Lake Mohave is the largest remaining in the entire Colorado River Basin. Observers reported these fish as being common to abundant when the reservoir was filling in the 1950s, with the number of adults appearing to remain fairly stable through the 1970's and 1980's (Minckley et al. 1991). No verified natural recruitment has been found in Lake Mohave despite documented spawning and the presence of larval fish (Minckley 1983; Marsh 1994). This failure to recruit has been attributed primarily to predation on razorback sucker larvae by nonnative fishes (Minckley et al. 1991; Burke 1994; Horn 1996; Pacey and Marsh 1998b). Estimates of the wild stock in Lake Mohave, now old and senescent, have dropped precipitously in recent years from 60,000 as late as 1991 to 25,000 in 1993 (Marsh 1993; Holden 1994) to about 9,000 in 2000 (personal communication, T. Burke, U.S. Bureau of Reclamation).

In Lake Mead, razorback sucker were reported to be common into the 1960's, but numbers were noticeably reduced by the 1970's, and the species is now considered rare (Minckley 1973; Bozek et al. 1991). Holden et al. (1999b) reported finding adult fish, many in spawning condition; larval fish; and a few juveniles in Lake Mead, primarily in Vegas Bay or Echo Bay, the two documented spawning sites in the reservoir. They estimate the combined population of these two spawning aggregations at around 400 adults. Recently collected age-growth data showed fish at about 20–25 years of age, indicating recent recruitment (Ruppert et al. 1999).

It is estimated that there are more than 1,000 razorback sucker in the 60-mile reach of the lower Colorado River between Davis Dam and Lake Havasu, with evidence of reproduction (Mueller 2001). These individuals do not include the fish in Lake Havasu.

Between 1981 and 1990, more than 13 million hatchery-produced razorback sucker were released at 57 sites into historic habitat in Arizona, primarily in the Verde, Gila, and Salt rivers and their tributaries, where the natural population had been extirpated (Hendrickson 1994). Low short-term survival and no long-term survival was reported from these releases, primarily because of predation by nonnative fishes, although 14 adults were recently reported from Fossil Creek. Since 1994, 17,371 razorback sucker have been stocked into the Verde River. Numerous fish have been recaptured and survival up to two years has been documented. In addition, ripe males have been encountered in the Verde River, but no evidence of reproduction or recruitment has been found (personal communication, D. Shroufe, Arizona Game and Fish Department). A major repatriation effort to conserve the gene pool of razorback sucker in Lake Mohave was initiated by the Native Fish Work Group in 1991, in which naturally hatched larvae are captured and raised to juveniles under protection from predators in isolated coves (Minckley et al. 1991; Clarkson et al. 1993; Burke 1994; Pacey and Marsh 1998b; Jahrke and Clark 2000). More than 23,000 repatriated juveniles were released into Lake Mohave between 1992 and 1998. A total of 212 repatriated fish had been recaptured from 1992 through 1999, representing about 1% of the total number of juveniles released. Using the wild adult population estimate of 9,087 and catch summaries from 1998 and 1999, Pacey and Marsh (1999) determined that the percentage of repatriated juveniles among total recaptures is about 34%. An estimate of the repatriated juvenile population size is thus 3,104 with a 13% survival. They estimate that there are currently 12,000 razorback sucker in Lake Mohave, 75% of those as wild adults and 25% as repatriated juveniles. Intensive management in some locations has helped to offset the decline of the razorback sucker, such as the capture and protective rearing of larvae in Lake Mohave for release at larger sizes, and raising of young in predator-free environments in Cibola High Levee Pond; a 2-ha pond containing approximately 3,000 razorback suckers with reproduction and recruitment (Marsh 2000).

In the Upper Colorado River Basin, the razorback sucker has declined in distribution and abundance until it is now found in small numbers only in the middle Green River, between the confluences of the Duchesne and Yampa rivers, and in the lower reaches of those two tributaries (Tyus 1987; Bestgen 1990). According to Modde and Irving (1998), tag capture and telemetry data support the hypothesis that razorback sucker in the middle Green River constitute a single reproductive population. Known spawning sites are located in the lower Yampa River and in the Green River near Escalante Ranch between river km 492 and 501, but other, less-used sites are probable (Tyus and Karp 1990; Modde and Wick 1997; Modde and Irving 1998). Lanigan and Tyus (1989) estimated the middle Green River population at 948 adults (95% confidence interval: 758–1,138). Modde et al. (1996) estimated this population at 524 adults, and characterized it as being stable or declining slowly with some evidence of recruitment. They attributed this suspected recruitment to unusually high spring flows during 1983–1986 that inundated portions of the floodplain used as nurseries by young.

In recent years, only small numbers of razorback sucker have been recorded in the lower Green River, where the capture of a few larvae and juveniles indicate probable spawning in the vicinity of the San Rafael River confluence (Gutermuth et al. 1994; Chart et al. 1999; Muth et al. 2000). Data are insufficient to estimate the number of adults in this reach (Minckley et al. 1991). Bestgen et al. (2002) estimated that the current population of wild adult razorback sucker in the middle Green River is about 100.

In the upper Colorado River, the number of razorback sucker captured has decreased dramatically since 1974. The wild population is considered extirpated from the Gunnison River, where records are limited to two fish captured in 1976 (Burdick and Bonar 1997). During a 2-year study (1979–1981), Valdez et al. (1982) captured only 52 individuals, all old adults, in a 465-km reach of the Colorado River from Hite, Utah, to Rifle, Colorado. Thirty-seven (71%) of these fish were found in two abandoned gravel pits in Grand Valley, Colorado, just upstream and downstream of the confluence with the Gunnison River. Four fish were captured in Lake Powell; two between Lake Powell and Moab, Utah; two just downstream of Grand Valley; two in the river in Grand Valley; and three between Grand Valley and Rifle. No razorback sucker were captured in the Gunnison River. Between 1984 and 1990, despite intensive collecting efforts, a total of only 12 individuals, including some in reproductive condition, were captured in Grand Valley (Osmundson and Kaeding 1991). No young razorback sucker have been captured anywhere in the upper Colorado River since the mid-1960's (Osmundson and Kaeding 1991).

Scientifically documented records of wild razorback sucker in the San Juan River are limited to two fish captured in 1976 in a riverside pond near Bluff, Utah, and one fish captured in the river in 1988, also near Bluff (Ryden 2000). No wild razorback sucker were found during the 7-year research period (1991–1997) of the San Juan River Basin Recovery Implementation Program (Holden 1999). Large numbers were anecdotally reported to have been found in a drained pond near Bluff in 1976, but no specimen was preserved to verify the presence of the species. Hatchery-reared razorback sucker, especially larger fish (> 350 mm), introduced into the San Juan River in the 1990's have survived into subsequent years and reproduced, as evidenced by recapture data and collection of larval fish (Ryden 2000).

The razorback sucker appear to be a highly diverse species, displaying many mtDNA genotypes. Based on restriction endonuclease analysis of mitochondrial DNA (mtDNA), it was determined that fish from Lake Mohave displayed the highest degree of genetic variability of all remaining populations of razorback sucker. Moving from south to north, populations appear to be progressively less diverse and possess fewer unique genotypes. Most fish sampled exhibited genotypes identical to those in the Lake Mohave fish; unique genotypes were similar and rarely found (Dowling and Minckley 1993). Hybridization between razorback sucker and flannelmouth sucker has been reported for many years (Hubbs and Miller 1953; Suttkus et al 1976; Kidd 1977; McAda and Wydoski 1980; Maddux et al. 1987; Valdez and Ryel 1995; Douglas and Marsh 1998), and identified in fish collected as early as 1889 (Hubbs and Miller 1953).

## A.3 Hybridization

The present levels of hybridization among razorback sucker and other catostomids is not considered a threat to the species. Hybridization between razorback sucker and flannelmouth sucker (a native of the Colorado River Basin) apparently occurred historically (Hubbs and Miller 1953). Hybridization of razorback sucker and nonnative white sucker (*Catostomus commersoni*) may be problematic for the razorback sucker in some parts of the upper basin. Abundance and distribution of white sucker and numbers of hybrids with flannelmouth sucker and bluehead sucker have increased substantially since about 1980 (Valdez et al. 1982; Masslich 1993). These reports demonstrate the capability for white sucker to hybridize with native Colorado River suckers, and suggests likely hybridization with razorback sucker as populations are expanded for recovery.

Based on external morphological characteristics, a high incidence of intercrosses was reported in the upper basin, including 16 intercrosses to 73 razorback sucker (Vanicek et al. 1970); 40 intercrosses to 53 razorback sucker (Holden 1973); and 8 intercrosses to 95 razorback sucker (McAda and Wydoski 1980). Recent electrophoretic analysis of Lake Mohave razorback sucker revealed less than a 5% incidence of flannelmouth sucker genes, a level of introgression considered insignificant (Buth et al. 1987). Of 2,619 unique individuals examined from the Little Colorado River and its confluence with the mainstem Colorado River in Grand Canyon, 2,578 were judged as flannelmouth sucker and 41 as putative razorback sucker/flannelmouth sucker hybrids, based on morphological characters, especially a razor nape (Douglas and Marsh 1998). Mitochondrial DNA, evaluated in 12 of the 41 putative hybrids, revealed that eight were of hybrid origin, but none was an $F_1$ hybrid. Instead, they were backcrossed with flannelmouth sucker to varying degrees (60–90%). This genetic analysis suggests that determination of hybrids from external morphological characters may overestimate the degree of hybridization between razorback sucker and flannelmouth sucker. It is unknown if anthropogenic changes throughout the basin have weaken reproductive isolating mechanisms and allowed a greater incidence of hybridization. Certainly, the potential for hybridization must be considered when introducing hatchery-reared razorback sucker to reestablish populations in habitat occupied by flannelmouth sucker.

## A.4 Habitat

The razorback sucker evolved in warm-water reaches of larger rivers of the Colorado River Basin from Mexico to Wyoming. Habitats required by adults in rivers include deep runs, eddies, backwaters, and flooded off-channel environments in spring; runs and pools often in shallow water associated with submerged sandbars in summer; and low-velocity runs, pools, and eddies in winter. Spring migrations of adult razorback sucker were associated with spawning in historic accounts, and a variety of local and long-distance movements and habitat-use patterns have been documented. Spawning in rivers occurs over bars of cobble, gravel, and sand substrates during spring runoff at widely ranging flows and water temperatures (typically greater than 14°C). Spawning also occurs in reservoirs over rocky shoals and shorelines. Young require nursery environments with quiet, warm, shallow water such as tributary mouths, backwaters, or inundated floodplain habitats in rivers, and coves or shorelines in reservoirs. Flow recommendations have been developed that specifically consider flow-habitat relationships in habitats occupied by razorback sucker in the upper basin, and were designed to enhance habitat complexity and to restore and maintain ecological processes (see section 4.1). The following is a description of observed uses in various parts of the Colorado River Basin.

Adult razorback sucker tend to occupy different habitats seasonally (Osmundson et al. 1995; Table A-1), and can do well in both lotic and lentic environments (Minckley et al. 1991). In rivers, they usually are captured in lower velocity currents, more rarely in turbulent canyon reaches (Tyus 1987; Lanigan and Tyus 1989; Tyus and Karp 1990; Bestgen 1990; Minckley et al. 1991). An exception may be in the San Juan River, where hatchery-reared, radio-tagged adults preferred swifter mid-channel currents during summer–autumn base-flow periods (Ryden 2000). In the upper basin, bottomlands, low-lying wetlands, and oxbow channels flooded and ephemerally connected to the main channel by high spring flows appear to be important habitats for all life stages of razorback sucker (Modde et al. 1996; Muth et al. 2000). These areas provide warmwater temperatures, low-velocity flows, and increased food availability (Tyus and Karp 1990; Modde 1997; Wydoski and Wick 1998). For example, in Old Charlie Wash, a managed wetland on the middle Green River, spring–summer water temperatures were 2–8°C higher than in the adjacent river (Modde 1996, 1997), density of benthos was 41 times greater than in other sampled habitats, and densities of zooplankton were 29 times greater than in backwaters and 157 times greater than in the main channel (Mabey and Shiozawa 1993).

Many floodplain habitats comparable to Old Charlie Wash were available in the Green and Colorado River systems before dams, channelization, and levees altered large segments of the ecosystem (Tyus and Karp 1990; Osmundson and Kaeding 1991; Wydoski and Wick 1998). The loss of such habitats has been implicated in the decline of the species, but to some degree gravel pits and other artificial, relatively warm off-channel ponds are used as a substitute (Valdez and Wick 1983; Wick 1997; Maddux et al. 1993; Minckley et al. 1991).

Table A-1. Seasonal frequency (%) of use of macrohabitats in the Grand Valley of the upper Colorado River subbasin by radio-tagged adult razorback sucker, 1986–1989 (Osmundson et al. 1995). Habitats: FR = fast runs, SR = slow runs, RA = rapids, RI = riffles, ED = eddies, PO = pools, SH = shorelines, BA = backwaters, and GP = off-channel flooded gravel pits.

| Months | Habitats | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | FR | SR | RA | RI | ED | PO | SH | BA | GP |
| April–June (Spring) | 0–11 | 0–34 | 0 | 0 | 0–7 | 0–67 | 0–9 | 17–45 | 0–43 |
| July | 0 | 29 | 0 | 7 | 0 | 21 | 7 | 36 | 0 |
| August–October (Summer) | 0 | 33–75 | 0 | 0 | 0–13 | 13–67 | 0 | 0 | 0 |
| November–March (Winter) | 0 | 0–50 | 0 | 0 | 0–33 | 50–100 | 0 | 0–10 | 0 |

Razorback sucker breed in spring, when flows in riverine environments are high. During that time of year, researchers in the upper basin have documented movement of adults into flooded bottomlands and gravel pits, backwaters, and impounded tributary mouths near spawning sites (Holden and Crist 1981; Valdez and Wick 1983; Tyus 1987; Osmundson and Kaeding 1989; Tyus and Karp 1990; Modde and Wick 1997; Modde and Irving 1998; Osmundson et al. 1995). Temperature is an important aspect of habitat for razorback sucker. Thermal preference for adults was 22.9–24.8°C, based on electronic shuttle box studies, and lower avoidance temperature was 8.0–14.7°C and upper avoidance temperature was 27.4–31.6°C (Bulkley and Pimentel 1983).

During breeding season (mostly April–June), when river flows are high, adult razorback sucker congregate in flooded bottomlands and gravel pits, backwaters, and impounded tributary mouths near spawning sites (Holden and Crist 1981; Valdez and Wick 1983; Tyus 1987; Osmundson and Kaeding 1989; Tyus and Karp 1990; Osmundson et al. 1995; Modde and Wick 1997; Modde and Irving 1998). Within the last 20 years, relatively large aggregations of razorback sucker have been observed in these types of environments, usually upstream of areas with broad floodplains (Tyus et al. 1982; Valdez et al. 1982; Modde et al. 1996; Muth 1995). Razorback sucker adults occupy such habitats both before and after spawning, presumably for feeding, resting, gonadal maturation, and other activities associated with their reproductive cycle (Tyus and Karp 1990; Osmundson and Kaeding 1991; Modde and Wick 1997; Modde and Irving 1998). On the upper Colorado River, peak use of backwater and gravel pit habitats occurred in June (Osmundson et al. 1995). Ryden (2000) recorded somewhat similar behavior among introduced razorback sucker in the San Juan River, where radiotelemetered adults chose habitats warmer than the main channel in March–April; eddies during the ascending limb of the hydrograph in May; and low-velocity habitats along the river margin, including inundated vegetation, during the highest flows in June. The fish moved back into eddies on the descending limb of the hydrograph in July.

Spawning has not been observed directly in the upper basin, but aggregations of ripe razorback sucker indicate that spawning occurs in broad alluvial, flat-water regions over large gravel-cobble bars and coarse sand substrates at water temperatures of 6–19°C in velocities <1.0 m/s and depths of <1.0 m (McAda and Wydoski 1980; Tyus 1987; Tyus and Karp 1990; Bestgen 1990; Snyder and Muth 1990). Studies suggest a linkage between egg survival and cleansing of substrates by high spring flows. Eggs deposited on substrates with moderate to high sediment have lower survival because of suffocation (Wick 1997). Young razorback sucker are thought to occupy shallow, warm, low-velocity habitats in littoral zones, backwaters, and inundated floodplains and tributary mouths downstream of spawning bars. This inference is based on the few larval and young juveniles collected in the upper basin, observations of hatchery-reared fish, and analogy with other native fish in the Colorado River system (Smith 1959; Sigler and Miller 1963; Taba et al. 1965; Minckley 1973; Tyus 1987; Modde 1996, 1997; Muth et al. 1998). Young-of-year appear to stay in these sheltered habitats for several weeks after hatching, then disperse to deeper water (Minckley et al. 1991). In lakeside rearing ponds in the lower basin, juvenile razorback sucker hide during the day in dense aquatic vegetation, under debris, and in rock cavities (U.S. Bureau of Reclamation 1996).

During non-reproductive times of the year (summer–winter), adult razorback sucker in lotic environments have been found in deeper eddies, slow runs, backwaters, and other types of pool habitats with silt or sand substrate, depths ranging from 0.6 to 3.4 m, and velocities ranging from 0.3 to 0.4 m/s (Valdez et al. 1982; Tyus 1987; Tyus et al. 1987; Tyus and Karp 1990; Minckley et al. 1991; Osmundson et al. 1995). In summer, Osmundson and Kaeding (1989) captured adults in pools and runs 1.62 to 1.65 m deep. Tyus and Karp (1990) also found them in the vicinity of midchannel sandbars. In winter, Osmundson and Kaeding (1989) captured adults in pools and slow eddies 1.83 to 2.16 m deep, and Valdez and Masslich (1989) found them in slow runs, slack water, and eddies 0.6 to 1.4 m deep during winter.

Hatchery-reared adults in the San Juan River generally moved out of the main channel and into edge pools during low winter base flows, using these habitats exclusively in January, the coldest month of the study (Ryden 2000). During the other winter months, fish ventured into the main channel during the warmest part of the day, presumably to feed. In the Verde River, adult razorback sucker were found in deeper pools and glides, at depths generally less than those reported in the upper basin (Creef et al. 1992; Clarkson et al. 1993). This difference was attributed to generally shallower conditions and possibly to hatchery conditioning (Clarkson et al. 1993). In the Gila River, Marsh and Minckley (1991) captured razorback sucker in flatwater, pools, and eddies.

In reservoirs in the lower basin, adult razorback sucker are pelagic at varying depths, except in breeding season, when they congregate in shallower, nearshore areas (Pacey and Marsh 1998b). Spawning takes place near shore in shallow water at temperatures of 10–21°C, over flat, gravel and gravel mix substrate (Bozek et al. 1991; Minckley 1983; Schrader 1991; Burke and Mueller 1993). These areas tend to be located on outwash fans, along shorelines or on shoals, that are swept free of silt by currents, wave action, and spawning activity. Larvae remain near shore for a few weeks before disappearing (Bozek et al. 1990, 1991; Minckley et al. 1991; Schrader 1991; Marsh and Minckley 1989; Burke and Mueller 1993). What happens to them is unknown; they may be dispersing to deeper water, but the near absence of juveniles suggests mortality at the larval stage, probably as a result of predation (Marsh and Langhorst 1988; Minckley et al. 1991; Horn 1996). Five tagged juveniles in Lake Mohave moved throughout the pelagic zones for the first week after release but then tended to occupy vegetated areas near the shore (Mueller et al. 1998).

In the mixed channelized, lacustrine, and backwater environment of the Imperial Division of the Lower Colorado River, Bradford et al. (1999) tracked 58 fish with ultra-sonic tags and found that the main channel was used less frequently in proportion to availability; side channels were used in proportion to availability; backwaters were used slightly more relative to availability; and the reservoir was used more frequently in proportion to availability.

### A.5 Movement

To complete all life-history requirements, razorback sucker move between adult, spawning, and nursery habitats (Maddux et al. 1993). Some fish appear to have relatively short home ranges (Kidd 1977; Tyus 1987; Kaeding and Osmundson 1988; Myer and Moretti 1988; Creef et al. 1992). Other razorback sucker have been documented to move great distances. Tyus (1987), for example, reported that 28 of 52 tagged fish moved an average of 60 km over as much as 8 years. The greatest net movements were 192 km over 4 years and 206 km over 5 years.

In both lotic and lentic environments, adults have been documented to travel to aggregate near spawning sites (Minckley et al. 1991; Modde and Wick 1997; Modde and Irving 1998; Mueller et al. 2000). Historic reports of large numbers of adult razorback sucker amassed in a single location are attributable to spawning runs and aggregations (Jordan 1891; Hubbs and Miller 1953; Sigler and Miller 1963; McAda and Wydoski 1980). Movement into these staging areas in spring appears to be related primarily to increases in river discharge and secondarily to increases in water temperature (Tyus and Karp 1990; Modde and Wick 1997; Muth et al. 2000). Flow and water temperature cues may play an important role prompting razorback adults to aggregate prior to spawning (Muth et al. 2000).

The longest distances moved by razorback sucker in the Green River were covered by males just before and after spawning (Modde and Wick 1997; Modde and Irving 1998). After spawning in the middle Green River, adults tended to move downstream, commonly traveling over 100 km. Some fish were observed to return upstream to within 50 km of the original spawning site (Tyus and Karp 1990; Modde and Wick 1997). Measured distances traveled by adults in the upper basin include 30–106 km (Tyus and Karp 1990), 26–138 km (McAda and Wydoski 1980), and 11–19 km (Osmundson and Kaeding 1989). Such migratory spawning behavior is consistent with studies of other riverine catostomid (Tyus 1985).

Except during periods before and after spawning, adult razorback sucker are thought to be relatively sedentary (Tyus 1987; Tyus and Karp 1990). Adults tracked in the Yampa River in summer remained mostly in quiet water near shore, never moving more than 0.5 km; one fish occasionally visited a gravel bar in faster water (McAda and Wydoski 1980). In the winter in the Green River, most fish tracked traveled less than 5 km, with movement correlated with changing flows that shifted ice (Valdez and Masslich 1989). Individual adults were also reported returning yearly to overwinter in the same locations within canyon areas.

Adult razorback sucker also aggregate to spawn in lacustrine environments (Jonez and Sumner 1954; Bozek et al. 1984). Holden et al. (1999b) tracked 21 adults as far as 24 km away from the release site. At times other than the spawning period, tagged fish occupied areas that were 8–19 km away from known spawning sites. Females in Lake Mohave were found to move significant distances during peak reproduction (Mueller et al. 2000). Hatchery-reared razorback sucker released directly into the wild exhibited a "fright response", but fish acclimated on-site in holding pens prior to release moved far less distance from the release site (Foster and Mueller 1999; Mueller and Foster 1999).

## A.6 Reproduction

In upper basin riverine environments, razorback sucker in reproductive condition and newly hatched larvae generally have been captured mid-April through June on the ascending limb of the hydrograph (McAda and Wydoski 1980; Valdez et al. 1982; Tyus 1987; Osmundson and Kaeding 1989; Tyus and Karp 1989, 1990; Snyder and Muth 1990; Osmundson and Kaeding 1991; Modde and Wick 1997; Muth et al. 1998). In Lake Mead, spawning takes place earlier, from mid-February to early June, peaking in March–April (Jonez and Sumner 1954; Holden et al. 1999a). Spawning occurs even earlier in Lake Mohave, beginning as early as November and continuing as late as May (Minckley et al.1991; Schrader 1991; Bozek et al. 1990, 1991; Burke and Mueller 1993). Activity appears to peak in January–March, with only scattered individuals in spawning condition found in May (Bozek et al. 1991).

Evidence of spawning in the Green River has been observed at water temperatures of 6–19°C (McAda and Wydoski 1980; Tyus and Karp 1990; Snyder and Muth 1990; Muth et al. 1998), with an average of about 15°C reported by Tyus and Karp (1990). Spawning in Lake Mohave has occurred at water temperatures between 9.5°C and 22°C (Minckley et al. 1991; Schrader 1991; Bozek et al. 1991; Burke and Mueller 1993). Gorman et al. (1999) observed spawning in the tailwaters of Hoover Dam at water temperatures of 11–12°C. The population was characterized by a preponderance of spent/non-ripe males and gravid females, an unusual condition for suckers so late in the spawning season and possible evidence of retarded ovulation due to the cold dam tailwaters. Optimal water temperatures for hatching success is around 20°C; extreme limits of hatching are 10°C and 30°C (Marsh and Minckley 1985). Snyder and Muth (1990) found that eggs incubated at 18–20°C hatch in 6–7 days, swim up in 12–13 days, and swim down in 27 days; eggs incubated at 15°C hatch in 11 days, swim up in 17–21 days, and swim down in 38 days. Bozek et al. (1984) reported that eggs incubated at 10°C hatched in 17.5–22.1 days, whereas Toney (1974) reported high mortality for eggs incubated at 11.7°C.

Razorback sucker have high reproductive potential. McAda and Wydoski (1980) reported an average fecundity (N=10) of 46,740 eggs/fish (27,614–76,576), or about 39,600 eggs/kg. Inslee (1981) reported an average of 103,000 eggs/fish. Razorback sucker are broadcast spawners that scatter adhesive eggs over cobble substrate. Eggs incubate in interstitial spaces, and larvae must hatch and emerge from cobble substrates before being suffocated by deposited silt/sand

(Minckley 1983; Minckley et al. 1991; Wick 1997). Adults make no effort to guard the nest sites (Jonez and Sumner 1954).

## A.7 Survival

Using data from 1980–1992, Modde et al. (1996) estimated annual survival of wild, adult razorback sucker in the middle Green River to be 71%. The extremely low recruitment in wild populations of this species is thought to be the result of low survival in early life stages (Muth et al. 2000). In the middle Green River, larvae apparently disappear from nursery habitats by early or mid-June (Muth et al. 1998). In Lake Mohave, larvae disappear from samples at about 10–13 mm TL (Minckley et al. 1991). Low survival of razorback sucker larvae has been attributed to loss of suitable nursery habitat and predation by nonnative fishes (Mueller and Burke 2001). Historically, inundated floodplains in both the upper and lower Colorado River basins provided warm, quiet, food-rich environments for larval razorback sucker. Currently, nursery habitats on the Green River consist mostly of backwaters, which may have insufficient numbers of planktonic and benthic organisms to meet nutritional needs of larval razorback sucker (Grabowski and Hiebert 1989; Papoulias and Minckley 1990; Mabey and Shiozawa 1993). Pacey and Marsh (1998a), however, pointed out that *"in every instance, fish survive (often to sexual maturity) in backwater habitats free of nonnative predators."* Nutritional limitations may contribute to mortality of larvae in Lake Mohave, but Horn (1996) concluded that "starving or not" all razorback sucker larvae appear to be consumed by nonnative fish predators. Larval razorback sucker are extremely susceptible to predation in clear water like that of lower basin reservoirs (Johnson and Hines 1999).

Stocked razorback sucker suffered virtually 100% mortality when small fish were used, but survivorship has increased with use of larger fish less susceptible to predation (Marsh and Langhorst 1988; Marsh and Brooks 1989; Minckley et al. 1991; Burke 1994; Horn 1996; Pacey and Marsh 1998b; Marsh 1999; Jahrke and Clark 2000). In a study of stocked razorback sucker in the San Juan River, Ryden (2000) found that fish < 351 TL comprised 68.3% of stocked fish but only 9.3% of recaptures, whereas fish ≥400 mm comprised 85.2% of recaptures. He suggested that > 410 mm may be the predation threshold for razorback sucker in the San Juan River. Burdick and Bonar (1997) stocked adult razorback sucker (11–12 years old) from artificial ponds in the upper Colorado and Gunnison rivers. These fish suffered high rates of mortality within the first year, 85% and 88%, respectively. Low survivorship may be attributable to inability of fish reared in artificial conditions to adjust to the flows, turbidity, temperature, water quality, and food base of a natural riverine environment (Ryden 2000).

## A.8 Predation

Nonnative fishes dominate the ichthyofauna of Colorado River Basin rivers, and certain species have been implicated as contributing to reductions in the distribution and abundance of native fishes (Carlson and Muth 1989). At least 67 species of nonnative fishes have been introduced into the Colorado River Basin during the last 100 years (Tyus et al. 1982; Carlson and Muth 1989; Minckley and Deacon 1991; Maddux et al. 1993; Tyus and Saunders 1996; Pacey and Marsh 1998a; Marsh et al. 2001). Tyus et al. (1982) reported that 42 nonnative fish species have become established in the upper basin, and Minckley (1985) reported that 37 nonnative fish species have become established in the lower basin. Many of these fishes were intentionally introduced as game or forage species, whereas others were unintentionally introduced with game species or passively as bait fish. Potential negative interactions (i.e., predation and competition) between nonnative and native fishes have been identified (reviewed by Minckley 1991; Hawkins and Nesler 1991; Lentsch et al. 1996; Tyus and Saunders 1996; Pacey and Marsh 1998a).

Razorback sucker in the upper basin live sympatrically with about 20 species of warm-water, nonnative fishes (Tyus et al. 1982; Lentsch et al. 1996) that are potential predators, competitors, and vectors for parasites and diseases. Hawkins and Nesler (1991) identified red shiner (*Cyprinella lutrensis*), common carp (*Cyprinus carpio*), fathead minnow (*Pimephales promelas*), channel catfish (*Ictalurus punctatus*), northern pike, and green sunfish (*Lepomis cyanellus*) as the nonnatives considered by Colorado River Basin researchers to be of greatest concern because of their suspected or documented negative interactions with native fishes. Sand shiner (*Notropis stramineus*), white sucker, black bullhead (*Ameiurus melas*), smallmouth bass (*Micropterus dolomieu*), and largemouth bass (*M. salmoides*) were identified by Hawkins and Nesler (1991) as nonnatives of increasing concern because of their increasing abundance, habitat preferences, and/or piscivorous habits. Lentsch et al. (1996) identified existing threats to native fishes in the upper basin from six species of nonnative fishes including red shiner, common carp, sand shiner, fathead minnow, channel catfish, and green sunfish.

Flooded bottomlands and other low-velocity shoreline habitats in alluvial reaches of the upper Colorado, Green, and San Juan rivers are important nursery areas for larval and juvenile razorback sucker (Holden 1999; McAda 2000; Muth et al. 2000). Researchers believe that nonnative fish species in those habitats limit the success of razorback sucker recruitment (e.g., Muth and Nesler 1993; Bestgen 1997; Bestgen et al. 1997; McAda and Ryel 1999; Valdez et al. 1999a). Adult red shiner are known predators of larval native fish in backwaters of the upper basin (Ruppert et al. 1993), and predation by nonnative fishes such as red shiner may influence within-year-class recruitment of razorback sucker.

In the lower basin, the recapture rate of razorback sucker stocked in the Salt and Verde rivers, Arizona, has been low. This low recapture rate has been attributed to severe predation by nonnative flathead catfish (*Pylodictis olivaris*; Hendrickson 1994). Hendrickson and Brooks (1987) documented predation by yellow bullhead (*Ameiurus natalis*) and largemouth bass on young razorback sucker stocked in the Verde River, Arizona.

### A.9 Age and Growth

Based on analysis of bony structures, including otoliths, from 70 razorback sucker from Lake Mohave, McCarthy and Minckley (1987) estimated ages ranging from 24 to 44 years. The relatively large size of wild adults in both the upper and lower basins, coupled with high incidences of blindness, external parasitism, tumors, and infections suggests that most populations are composed primarily of old fish (Valdez et al. 1982; Minckley 1983; Bozek et al. 1984; McCarthy and Minckley 1987). Razorback sucker in Lake Mead appear to be an exception. Ruppert et al. (1999) measured an annual average growth rate of 17.28 mm for wild (unstocked) razorback sucker in Lake Mead. This rapid growth is typical of young catostomid fish. Holden et al. (1999b) reported a lower annual growth rate (10 mm) from Lake Mead, but this is still three times the reported rate for both Lake Mohave and upper basin populations. Based on 10 years of data from Lake Mohave, Pacey and Marsh (1999) calculated an average monthly growth near zero (0.2–1.5 mm for females and 0.1–2.2 mm for males). In the upper basin, Modde et al. (1996) analyzed data from 1975–1992 and found the average growth rate to be only 1.66 mm/year.

Razorback sucker in the upper basin tend to be smaller than those in the lower basin, and grow more slowly (Minckley et al. 1991; Modde et al. 1996; Holden et al. 1999b). First-year growth of up to 400 mm was measured in the lower basin (Mueller et al. 1993), whereas average first-year growth of wild fish in the middle Green River was closer to 100 mm (Modde and Wydoski 1995). McAda and Wydoski (1980) reported that fish in upper basin riverine habitats mature after three to six growing seasons. In the lower basin, males usually reach maturity in their second year; females in their third year (U.S. Bureau of Reclamation 1996). Within the Green River, larvae in the upper river grew 6–21% faster than those in the lower river (Muth et al. 1998).

Rapid growth to adult size is correlated with food-rich, warm environments (Osmundson and Kaeding 1989; Minckley et al. 1991; Mueller 1995). Age-0 razorback sucker collected from Old Charlie Wash, a food-rich managed wetland adjacent to the middle Green River, grew 67% faster than larvae in hatchery ponds, and 29% faster than larvae in off-channel habitats (Muth et al. 1998). Enhanced growth is thought to increase survivorship, in part by reducing vulnerability to predation (Modde et al. 1999b). In laboratory experiments, slower larval growth of another native fish, Colorado pikeminnow, correlated to increased mortality due to predation (Bestgen et al. 1997).

Among stocked razorback sucker in the San Juan River, no difference was seen in growth between female and male fish, but, as expected, smaller fish grew faster than larger fish (Ryden 2000).

### A.10 Length-Weight and Condition Factor

No information is available on length-weight and condition factor of razorback sucker.

### A.11 Diet

All life stages of razorback sucker consume insects, zooplankton, phytoplankton, algae, and detritus; however, diet varies by age and habitat (Bestgen 1990, Muth et al. 2000). Within several days of hatching (10–11 mm TL), razorback sucker larvae begin to feed on plankton (Muth et al. 2000). As their terminal mouth migrates to a sub-terminal position, larvae begin feeding on benthos as well (Marsh and Minckley 1985). In riverine environments in the upper basin, Muth et al. (1998) reported that chironomids constituted the dominant food item in razorback sucker larvae of all lengths, but the proportion of diet they represented increased or remained the same with increasing fish length, whereas the relative importance of cladocerans, rotifers, and algae tended to decrease. Chironomids are among most common benthic invertebrates in riverine nursery habitats of the upper basin.

In Lake Mohave, Marsh and Langhorst (1988) reported a somewhat different diet for larvae < 21 mm TL. Larvae along a shoreline consumed primarily cladocerans, rotifers, or copepods; those in an adjacent backwater evidenced a similar diet, but ate larval chironomids and trichopterans as well. When compared to hatchery larvae, wild specimens had a significantly greater frequency of empty guts, and guts with food contained significantly fewer organisms. Zooplankton densities are relatively low and variable in Lake Mohave, but primary productivity is high. Minckley et al. (1991) reported that nutritional levels appear to be high enough in most years to support the new year class, but Horn (1996) concluded that nutritional limitations in the reservoir may contribute to mortality of larvae directly through starvation or indirectly through reduced growth, which prolongs their susceptibility to predation.

The diet of riverine adult razorback sucker consists mostly of benthic organisms (immature Ephemeroptera, Trichoptera, and Chironomidae) and lesser amounts of algae, detritus, and inorganic material (Bestgen 1990). Zooplankton is probably not well represented in the diet because it tends to be depauperate in riverine conditions that are often turbid and dynamic (Bestgen 1990). Razorback sucker feeding in rivers appear to bounce along the bottom, taking sediment into their mouths, and expelling it through their opercula while presumably retaining food items (Minckley 1973). They have been seen to burrow headfirst to depths of 10.0 cm. In contrast, Pacey and Marsh (1998b) reported that adult razorback sucker in a lacustrine environment (Lake Mohave) are primarily planktonic filter feeders, feeding at night throughout the water column. In a study of razorback sucker diet in Lake Mohave, Marsh (1987) found that the combination of planktonic crustaceans, rotifers, diatoms, detritus, and filamentous algae occurred in 44% of digestive tracts. *Bosmina* sp. was the most abundant item (100% of fish); followed by diatoms, primarily *Fragillaria crotenensis* (nearly 90%); and *Daphnia* sp. (72%). Rotifers, benthic ostracods, copepods, and chironomid dipteran larvae were found in 53%, 53%, 34%, and 3% of fish, respectively, but numbers were low, except for rotifers. Detrital organic matter and inorganic matter was found in 56% and 16% of digestive tracts, respectively.

## A.12 Parasites

There is no evidence that disease is a significant factor in the decline and status of the razorback sucker. In a survey of pathogens recovered from endangered fishes in the Upper Colorado River Basin, Flagg (1982) reported the bacteria *Erysipelothrix rhysiopathiae*, the protozoan *Myxobolus* sp., and the parasitic copepod *Lernaea cyprinacea* in razorback sucker. The protozoan parasite *Myxobolus* can invade the eye tissue and eventually cause blindness, an ailment commonly reported with older specimens (Minckley 1983). Based on incidence of infection and condition of fish, Flagg (1982) concluded that parasitic infestation was not likely to be a contributing factor to mortality of native fish in the upper basin.

In the lower basin, *Lernaea* spp., the pathogenic protozoans *Myxobolus* and *Ichtyophthirius*, an internal monogenetic trematode of the suborder Polyopistocotyles, the cestode *Isoglaridacris bulbocirrus*, and nematodes of the genus *Dacnitoides* have all been reported from razorback sucker from Lake Mohave (Minckley 1983; Bozek et al. 1984). Mpoame (1981) reported a low rate of parasitism for the Lake Mohave razorback sucker examined. This contrasts with hatchery-reared razorback sucker recaptured after introduction into the Verde and Salt Rivers, which exhibited extremely heavy infestations by *Lernaea*, particularly in summer and fall months (Creef and Clarkson 1993; Clarkson et al. 1993; Hendrickson 1994). The heavily infected fish (several dozen parasites per individual) were pale and emaciated, and two of them exhibited partial loss of equilibrium (Hendrickson 1994). Numerous heavily infected razorback sucker were found dead in trammel nets that were checked every 3 hours, while no other species suffered this type of mortality. Hendrickson (1994) concluded that razorback sucker may be more susceptible to *Lernaea* infection than other species in the stocked areas, and that *Lernaea* and other exotic parasites may have been a factor in the decline of native fish in the lower basin. *Lernaea* was not present or was very rare in Arizona before the 1930's, but had increased significantly by the 1960's (James 1968). Researchers monitoring reintroduced razorback sucker in the Verde and Salt rivers continued to observe *Lernaea* infestation on this species in 1999; however, the incidence appears to have decreased from previously reported levels (personal communication, E. Jahrke, Arizona Game and Fish Department).