# HUMPBACK CHUB (*Gila cypha*) RECOVERY GOALS

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# RECOVERY GOALS
## Amendment and Supplement to the Humpback Chub 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 1990 Humpback Chub 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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# ACKNOWLEDGMENTS


## Principal Authors of Original Draft Report

| | |
|---|---|
| Richard Valdez | R.A. Valdez and Associates |
| Ronald Ryel | Utah State University |
| Stephen Carothers | SWCA, Inc., Environmental Consultants |

## U.S. Fish and Wildlife Service Project Liaison, Coordination, and Legal Counsel

| | |
|---|---|
| Robert Muth | U.S. Fish and Wildlife Service, Region 6 |
| Thomas Czapla | U.S. Fish and Wildlife Service, Region 6 |
| Debbie Felker | U.S. Fish and Wildlife Service, Region 6 |
| Henry Maddux | U.S. Fish and Wildlife Service, Region 6 |
| Ralph Morgenweck | U.S. Fish and Wildlife Service, Region 6 |
| Susan Baker | U.S. Fish and Wildlife Service, Region 6 |
| Bob McCue | U.S. Fish and Wildlife Service, Region 6 |
| Sharon Rose | U.S. Fish and Wildlife Service, Region 6 |
| David Redhorse | U.S. Fish and Wildlife Service, Region 6 |
| John Antonio | U.S. Fish and Wildlife Service, Region 2 |
| Margot Zallen | Senior Attorney, Solicitor's Office |

## Technical Assistance

| | |
|---|---|
| Dorothy House | SWCA, Inc., Environmental Consultants |
| Matt Peterson | SWCA, Inc., Environmental Consultants |
| Bill McDavitt | SWCA, Inc., Environmental Consultants |
| Bryan Cowdell | SWCA, Inc., Environmental Consultants |

# ACKNOWLEDGMENTS (continued)

**The following individuals provided data, information, and reports, as well as reviews and comments, all which contributed to improving this document.**

| Individual | Affiliation |
|---|---|
| Kevin Bestgen | Colorado State University |
| Yvette Converse | U.S. Fish and Wildlife Service, Region 6 |
| James Deacon | University of Nevada Las Vegas |
| Thomas Dowling | Arizona State University |
| Chester Figiel | U.S. Fish and Wildlife Service, Region 2 |
| Lesley Fitzpatrick | U.S. Fish and Wildlife Service, Region 2 |
| Jennifer Fowler-Propst | U.S. Fish and Wildlife Service, Region 2 |
| Barry Gold | Grand Canyon Monitoring and Research Center |
| Steve Harris | Harris Water Engineering, Inc. |
| Phil Hedrick | Arizona State University |
| Paul Holden | Bio/West, Inc. |
| Stewart Jacks | U.S. Fish and Wildlife Service, Region 2 |
| Angela Kantola | U.S. Fish and Wildlife Service, Region 6 |
| Nancy Kaufman | U.S. Fish and Wildlife Service, Region 2 |
| Chris Keleher | Central Utah Water Conservancy District |
| Stuart Leon | U.S. Fish and Wildlife Service, Region 2 |
| Paul Marsh | Arizona State University |
| W.L. Minckley | Arizona State University |
| Gordon Mueller | U.S. Geological Survey |
| Bill Persons | Arizona Game and Fish Department |
| Frank Pfeifer | U.S. Fish and Wildlife Service, Region 6 |
| Barbara Ralston | Grand Canyon Monitoring and Research Center |
| Dave Soker | U.S. Fish and Wildlife Service, Region 6 |
| Lynn Starnes | U.S. Fish and Wildlife Service, Region 2 |
| Ray Tenney | Colorado River Water Conservation District |
| Manuel Ulibarri | U.S. Fish and Wildlife Service, Region 2 |
| Randy VanHaverbeke | U.S. Fish and Wildlife Service, Region 2 |
| Ed Wick | Independent contractor |

## Colorado River Fishes Recovery Team

| Member | Affiliation | Representing |
|---|---|---|
| Matthew Andersen | Utah Division of Wildlife Resources | Utah Division of Wildlife Resources |
| Rob Bettaso | Arizona Game and Fish Department | Arizona Game and Fish Department |
| Jim Brooks | U.S. Fish and Wildlife Service | USFWS, Region 2 |
| Tom Burke | U.S. Bureau of Reclamation | USBR, Lower Colorado River Region |
| Tom Chart | U.S. Bureau of Reclamation | USBR, Upper Colorado River Region |
| Kevin Christopherson | Utah Division of Wildlife Resources | Utah Division of Wildlife Resources |
| Rob Clarkson | U.S. Bureau of Reclamation | USBR, Lower Colorado River Region |
| Larry Crist | U.S. Bureau of Reclamation | USBR, Upper Colorado River Region |
| Terry Foreman | California Department of Fish and Game | California Department of Fish and Game |
| Chris Hayes | California Department of Fish and Game | California Department of Fish and Game |
| Kirk LaGory | Argonne National Laboratory | Western Area Power Administration |
| Chuck McAda | U.S. Fish and Wildlife Service | USFWS, Region 6 |
| Chuck Minckley | U.S. Fish and Wildlife Service | USFWS, Region 2 |
| Tom Nesler | Colorado Division of Wildlife | Colorado Division of Wildlife |
| Stephen Petersburg | National Park Service | NPS, Intermountain Region |
| David Propst | New Mexico Game and Fish Department | New Mexico Game and Fish Department |
| Jon Sjoberg | Nevada Division of Wildlife | Nevada Division of Wildlife |

## Biology Committee, Upper Colorado River Endangered Fish Recovery Program

| Member | Affiliation | Representing |
|---|---|---|
| Matthew Andersen | Utah Division of Wildlife Resources | State of Utah |
| Tom Chart | U.S. Bureau of Reclamation | USBR, Upper Colorado River Region |
| Kevin Christopherson | Utah Division of Wildlife Resources | State of Utah |
| Larry Crist | U.S. Bureau of Reclamation | USBR, Upper Colorado River Region |
| Bill Davis | Eco Plan Associates, Inc. | Colorado River Energy Distributors Assoc. |
| Paul Dey | Wyoming Game & Fish Department | State of Wyoming |
| John Hawkins | Colorado State University | Environmental Groups |
| Tim Modde | U.S. Fish and Wildlife Service | USFWS, Region 6 |
| Tom Nesler | Colorado Division of Wildlife | State of Colorado |
| Steve Petersburg | National Park Service | NPS, Intermountain Region |
| Tom Pitts | Water Consult Engineering & Planning | Upper Basin Water Users |
| Art Roybal | Western Area Power Administration | Western Area Power Administration |
| John Wulschleger | National Park Service | NPS, Intermountain Region |

## Management Committee, Upper Colorado River Endangered Fish Recovery Program

| Member | Affiliation | Representing |
|---|---|---|
| Susan Baker | U.S. Fish and Wildlife Service | USFWS, Region 6 |
| Thomas Blickensderfer | Colorado Department of Natural Resources | State of Colorado |
| Shane Collins | Western Area Power Administration | Western Area Power Administration |
| Christine Karas | U.S. Bureau of Reclamation | USBR, Upper Colorado River Region |
| Robert King | Utah Division of Water Resources | State of Utah |
| Dave Mazour | Tri-State Generation & Transmission | Colorado River Energy Distributors Assoc. |
| Bruce McCloskey | Colorado Division of Wildlife | State of Colorado |
| Clayton Palmer | Western Area Power Administration | Western Area Power Administration |
| Tom Pitts | Water Consult Engineering & Planning | Upper Basin Water Users |
| John Reber | National Park Service | NPS, Intermountain Region |
| John Shields | Wyoming State Engineer's Office | State of Wyoming |
| Hugh Thompson | Utah Department of Natural Resources | State of Utah |
| Brent Uilenberg | U.S. Bureau of Reclamation | USBR, Colorado Area |
| Robert Wigington | The Nature Conservancy | The Nature Conservancy |

## Implementation Committee, Upper Colorado River Endangered Fish Recovery Program

| Member | Affiliation | Representing |
|---|---|---|
| Kathleen Clark | Utah Department of Natural Resources | State of Utah |
| Rick Gold | U.S. Bureau of Reclamation | USBR, Upper Colorado River Region |
| Leslie James | Colorado River Energy Distributors Assoc. | Colorado River Energy Distributors Assoc. |
| Dan Luecke | Environmental Defense | Environmental Defense |
| Ralph Morgenweck | U.S. Fish and Wildlife Service | USFWS, Region 6 |
| Tom Pitts | Water Consult Engineering & Planning | Upper Basin Water Users |
| Dave Sabo | Western Area Power Administration | Western Area Power Administration |
| Patrick Tyrrell | Wyoming State Engineer's Office | State of Wyoming |
| Karen Wade | National Park Service | NPS, Intermountain Region |
| Greg Walcher | Colorado Department of Natural Resources | State of Colorado |

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# EXECUTIVE SUMMARY

This document amends and supplements the Humpback Chub Recovery Plan of 1990. The purpose of this document is to describe site-specific management actions/tasks; provide objective, measurable recovery criteria; and provide an estimate of the time to achieve recovery of the endangered humpback chub (*Gila cypha*), according to Section 4(f)(1) of the Endangered Species Act of 1973, as amended. Recovery or conservation programs that include the humpback chub will direct research, management, and monitoring activities and determine costs associated with recovery.

**Current Species Status:** The humpback chub 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 480 mm total length (TL) and 1.2 kg in weight. Six extant wild populations are known: (1) Black Rocks, Colorado River, Colorado; (2) Westwater Canyon, Colorado River, Utah; (3) Yampa Canyon, Yampa River, Colorado; (4) Desolation/Gray Canyons, Green River, Utah; (5) Cataract Canyon, Colorado River, Utah; and (6) the mainstem Colorado River in Marble and Grand Canyons and the Little Colorado River, Arizona. The first five populations are in the Upper Colorado River Basin (i.e., upstream of Glen Canyon Dam, Arizona), and the sixth population is in the Lower Colorado River Basin.

**Habitat Requirements and Limiting Factors:** Populations of humpback chub are restricted to deep, swift, canyon-bound regions of the mainstem and large tributaries of the Colorado River Basin. Adults require eddies and sheltered shoreline habitats maintained by high spring flows. These high spring flows maintain channel and habitat diversity, flush sediments from spawning areas, rejuvenate food production, and form gravel and cobble deposits used for spawning. Spawning occurs on the descending limb of the spring hydrograph at water temperatures typically between 16 and 22°C. Young require low-velocity shoreline habitats, including eddies and backwaters, that are more prevalent under base-flow conditions. Threats to the species include streamflow regulation, habitat modification, predation by nonnative fish species, parasitism, hybridization with other native *Gila*, and pesticides and pollutants.

**Recovery Objective:** Downlisting and Delisting.

**Recovery Criteria:** Objective, measurable criteria for recovery of humpback chub in the Colorado River Basin are presented for each of 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 Lake Mead National Recreation Area) 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 humpback chub biology. The humpback chub 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. If DPSs are designated, criteria for recovery of humpback chub will need to be reevaluated. These recovery goals are based on the best available scientific information, and are structured to attain a balance between reasonably achievable criteria (which include an acceptable level of uncertainty) and ensuring the viability of the species beyond delisting. Additional data and improved understanding of humpback chub biology may prompt future revision of these recovery goals.

Downlisting can occur if, over a 5-year period: (1) the trend in adult (age 4+; ≥200 mm TL) point estimates for each of the six extant populations does not decline significantly; and (2) mean estimated recruitment of age-3 (150–199 mm TL) naturally produced fish equals or exceeds mean annual adult mortality for each of the six extant populations; and (3) two genetically and demographically viable, self-sustaining core populations are maintained, such that each point estimate for each core population exceeds 2,100 adults (2,100 is the estimated minimum viable population [MVP] needed to ensure long-term genetic and demographic viability); 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) the trend in adult point estimates for each of the six extant populations does not decline significantly; and (2) mean estimated recruitment of age-3 naturally produced fish equals or exceeds mean annual adult mortality for each of the six extant populations; and (3) three genetically and demographically viable, self-sustaining core populations are maintained, such that each point estimate for each core population exceeds 2,100 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 humpback chub 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. 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.
2. Investigate the role of the mainstem Colorado River in maintaining the Grand Canyon population.
3. Investigate the anticipated effects of and options for providing warmer water temperatures in the mainstem Colorado River through Grand Canyon.
4. Ensure adequate protection from overutilization.

5. Ensure adequate protection from diseases and parasites.
6. Regulate nonnative fish releases and escapement into the main river, floodplain, and tributaries.
7. Control problematic nonnative fishes as needed.
8. Minimize the risk of increased hybridization among *Gila* spp.
9. Minimize the risk of hazardous-materials spills in critical habitat.
10. Provide for the long-term management and protection of populations and their habitats beyond delisting (i.e., conservation plans).

**Estimated Time to Achieve Recovery:** Reliable population estimates, based on a multiple mark-recapture model, are needed for all six extant 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. First reliable point estimates are expected for all populations by 2002. If those estimates are acceptable to the Service and all recovery criteria are met, downlisting could be proposed in 2007 and delisting could be proposed in 2010. This estimated time frame is based on current understanding of the status and trends of populations and on the monitoring time required to meet the downlisting and delisting criteria.

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# 1.0 INTRODUCTION

## 1.1 Background

The humpback chub (*Gila cypha*) is a large cyprinid fish endemic to the Colorado River Basin (Miller 1946). Adults attain a maximum size of about 480 mm total length (TL) and 1.2 kg in weight (Valdez and Ryel 1997). The humpback chub is currently listed as "endangered" under the Endangered Species Act of 1973, as amended (ESA; 16 U.S.C. 1531 *et. seq.*). It was first included in the List of Endangered Species issued by the Office of Endangered Species on March 11, 1967 (32 FR 4001) and was considered endangered under provisions of the Endangered Species Conservation Act of 1969 (16 U.S.C. 668aa). The humpback chub was included in the United States List of Endangered Native Fish and Wildlife issued on June 4, 1973 (38 FR No. 106), and it received protection as endangered under Section 4(c)(3) of the original ESA of 1973. The latest revised humpback chub recovery plan was approved on September 19, 1990 (U.S. Fish and Wildlife Service 1990a). 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 humpback chub 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 bonytail (*Gila elegans*), Colorado pikeminnow (*Ptychocheilus lucius*; formerly Colorado squawfish; Nelson et al. 1998), and razorback sucker (*Xyrauchen texanus*). The native fish assemblage of the Colorado River Basin is jeopardized by large mainstem dams, water diversions, 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 Humpback Chub Recovery Plan of 1990 (Recovery Plan; U.S. Fish and Wildlife Service 1990a). 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 humpback chub; 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 humpback chub (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 in balance with available estimates of carrying capacity. 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 humpback chub. 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

Three of the five major endangered-species recovery or conservation programs in the Colorado River Basin include the humpback chub (highlighted in Box 1). These are the Upper Colorado River Endangered Fish Recovery Program (UCRRP), the Glen Canyon Dam Adaptive Management Program (GCDAMP), 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

**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)***

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. As stated in the governing document of the UCRRP (U.S. Department of the Interior 1987), 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 will continue through 2011 under legislation passed in October 2000 (P.L. 106-392); Congress will review the UCRRP 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 conducted 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 1995), 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 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); coverage by GCDAMP and MSCP overlaps by approximately 50 km between the full pool elevation at Separation Canyon and the Lake Mead National Recreation Area near Emery Falls. The humpback chub is one of 56 species proposed for coverage by the MSCP, but it is not 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 humpback chub, 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 1990b), *"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 humpback chub, 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 humpback chub 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 humpback chub 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 and upper Colorado River subbasins; and the lower basin, including the mainstem and its tributaries from Glen Canyon Dam downstream to Lake Mead National Recreation Area) to address unique threats and site-specific management actions necessary to minimize or remove those threats. The recovery units encompass three management areas under different and separate recovery or conservation programs (i.e., UCRRP, GCDAMP, 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 humpback chub 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 humpback chub 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; 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). This section discusses the development of genetic and demographic viability standards for achieving the primary objective of the Recovery Plan, i.e., *"...the protection or restoration of...viable, self-sustaining populations..."* (U.S. Fish and Wildlife Service 1990a). Guidelines for population viability and self-sustainability 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). Most humpback chub populations do not appear to be severely depleted, based on the presence of six wild self-sustaining populations (see section 3.1.2). However, the current status of the species is being evaluated through population estimates.

In contrast, population persistence decreases linearly with environmental uncertainty (Shaffer 1987) and thus is of more concern for population viability of humpback chub. 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 humpback chub 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 humpback chub, but relatively stable numbers of adults in most populations suggest that adult mortality is compensated by recruitment of new individuals. For humpback chub, it is doubtful that environmental uncertainty will affect populations that meet genetic considerations if the environment is protected and secured against changes that exceed environmental stochasticity for the species; e.g., anthropogenic changes such as dams and introductions of nonnative fish species can impose environmental conditions that exceed the range of conditions experienced by the species historically.

Of most concern to the viability of humpback chub populations are catastrophic events. Regular catastrophic events are not expected for humpback chub, but infrequent and unpredictable events are possible. Although the species is long-lived (20+ years), catastrophic events may impact all life stages. Of greatest concern is invasion by a predator or competitor that effectively removes one or more age classes, a parasite or disease that kills much of the population, or exposure to toxic substances. Because the adult population size may have little effect on population persistence from a catastrophic event, a larger individual population provides little gain in viability (Ewens 1989). Therefore, multiple, demographically viable populations are necessary to reduce the probability of extinction of a species if the populations are relatively independent in their susceptibility to a catastrophic event (Goodman 1987; Shaffer 1987).

### *3.1.2 Existing populations of humpback chub*

Six self-sustaining populations of humpback chub are known to exist. Each of these populations consists of a discrete reproducing group of fish, with independent stock-recruitment dynamics, and is geographically separated from other populations. Five of the populations occur in the upper basin recovery unit: (1) Black Rocks, Colorado River, Colorado; (2) Westwater Canyon, Colorado River, Utah; (3) Yampa Canyon, Yampa River, Colorado; (4) Desolation/Gray Canyons, Green River, Utah; and (5) Cataract Canyon, Colorado River, Utah (Figure 1; Appendix A; Valdez and Clemmer 1982; U.S. Fish and Wildlife Service 1990a). The only population in the lower basin recovery unit occurs in the mainstem Colorado River in Marble and Grand Canyons and the Little Colorado River (LCR). This designation of populations differs from that presented in the Recovery Plan. The Recovery Plan identifies distribution of humpback chub in seven locations: (1) the LCR, (2) Colorado River in Marble and Grand


Figure 1. Distribution of humpback chub in the Colorado River Basin.

Canyons, (3) Cataract Canyon, (4) Black Rocks and Westwater Canyon, (5) Desolation/Gray Canyons, (6) Green River in Dinosaur National Monument, and (7) Yampa Canyon. Designation of populations in Cataract Canyon, Desolation/Gray Canyons, and Yampa Canyon in the Recovery Plan are consistent with this amendment and supplement. However, recent studies (Douglas and Marsh 1996 ;Valdez and Ryel 1995, 1997) show that humpback chub aggregations in the mainstem Colorado River in Marble and Grand Canyons are largely supported by reproduction and recruitment from the LCR, and hence, fish in these two systems are treated collectively as one Grand Canyon population in this document. The relationship between the reproducing population of humpback chub in the LCR and humpback chub in the Colorado River through Marble and Grand Canyons is not completely understood. Ongoing field investigations and stock-synthesis models reveal that the mainstem may be important habitat for large subadults and adults that spawn in the LCR (personal communication, L. Coggins, U.S. Geological Survey). Conversely, populations in Black Rocks and Westwater Canyon lack sufficient exchange of individuals for common stock-recruitment dynamics, and are considered separate populations in this document. Only small numbers of humpback chub have been captured in the Green River in Dinosaur National Monument (Vanicek et al. 1970; Holden and Stalnaker 1975b), and this area is not considered to currently support a population.

Recent preliminary estimates of abundance summed for the six humpback chub populations range from 7,300 to 13,800 wild adults. The precision and reliability of these estimates vary, and approximate numbers are provided as a general indication of the size of populations in the basin. Estimates of subadults are not currently available for all populations, and precise estimates of adults and subadults will be developed in order to determine if demographic criteria are met for downlisting and delisting. Estimates of adults in the six populations are: Black Rocks, 900–1,500 (Pfeifer et al. 1998; Nesler 2000; personal communication, C. McAda, U.S. Fish and Wildlife Service); Westwater Canyon, 2,000–5,000 (Chart and Lentsch 1999; personal communication, M. Hudson, Utah Division of Wildlife Resources); Yampa Canyon, 400–600 (Nesler 2000; personal communication, T. Modde, U.S. Fish and Wildlife Service); Desolation/Gray Canyons, 1,500 (Chart and Lentsch 2000); Cataract Canyon, 500 (Valdez 1990); and Grand Canyon, 2,000–4,700 (Douglas and Marsh 1996 [includes some subadults]; Valdez and Ryel 1997; personal communication, L. Coggins, U.S. Geological Survey).

### *3.1.3 Populations of humpback chub 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).

Humpback chub occur as multiple, demographically independent populations in widely distributed regions of the Colorado River Basin; distances of 17–394 km separate adjacent populations. This widely clumped distribution pattern contributes to redundancy as species protection against threats and catastrophic events. The five populations in the upper basin occur in discrete regions of three subbasins, including three populations in the Colorado River, and one population each in the Green River and Yampa River. The lower basin population in Grand Canyon exists independently downstream of Glen Canyon Dam, where it has been geographically isolated from upper basin populations since dam construction in 1963. This pattern of geographic separation among all six populations provides population redundancy and greatly reduces the likelihood of a catastrophic event simultaneously affecting the majority of populations.

It is recognized that the six populations of humpback chub vary considerably in size, from about 400 to 5,000 adults. The larger populations are considered "core populations". A core population is an independent self-sustaining population sufficiently large to maintain genetic and demographic viability. A core population may serve as a center of dispersal from which new populations are established or existing populations are augmented. Core populations are sufficiently large and viable to protect against extreme demographic and environmental variability. A core population may consist of two or more geographically proximate populations (e.g., Black Rocks and Westwater Canyon). In case of a catastrophe, multiple or redundant core populations preserve species viability.

Existing core populations of humpback chub are Westwater Canyon/Black Rocks with an estimated range of about 2,900 to 6,500 adults and Grand Canyon with about 2,000–4,700 adults (see section 3.3 — Genetic Viability). A third potential core population is Desolation/Gray Canyons, with a current estimate of 1,500 adults; this population is believed to be larger, and more precise mark-recapture estimates are to be conducted beginning in 2002. Each of these core populations is located in a geographically separate region of the Colorado River Basin, such that no single threat is likely to affect more than one of these cores.

### *3.1.4 Humpback chub 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.

Humpback chub exist as discrete populations with limited dispersal, even between adjacent and close populations (e.g., Black Rocks and Westwater Canyon). Dispersal rates observed in humpback chub populations may be enough to provide sufficient genetic exchange (i.e., one migrant per generation time; Mills and Allendorf 1996), but do not appear to be sufficient to provide effective metapopulation dynamics. Metapopulation dynamics may allow for repopulation of habitat patches over long periods of time, but the low dispersal rate of humpback chub will require considerable time for this phenomenon to effectively replace populations devastated by catastrophes.

## 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 humpback chub 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. Based on the highest recent preliminary estimates of abundance, the Black Rocks, Westwater Canyon, and Grand Canyon (in the LCR) populations support similar densities of adults (i.e., 300–400/km); however, densities in the other populations are substantially lower. Carrying capacity, as a function of recovery, must be considered on its own merits for each population.

## 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). Genetic concepts that were considered are summarized in Box 3.

### *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

**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.

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 humpback chub precludes a specific determination of $N_e$ at this time. In the absence of this information, $N_e$ for humpback chub 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), therefore an $N_e$ of 500 was used to derive an estimate of the number of adults needed to maintain genetic viability of a population of humpback chub. Recent research by fish geneticists support use of the 50/500 rule (Reiman and Allendorf 2001).

It is important to note that the number of individuals in a population required to achieve a genetic effective population size of 500 may be several times greater than 500 (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 $N_e$. The commonly observed sex ratio of wild humpback chub populations is 1:1 (Valdez and Ryel 1997). With a 1:1 sex ratio, an $N_e$ of 500 adults would consist of 250 males and 250 females. 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 humpback chub 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 1; 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 humpback chub needed to support an $N_e$ of 500. Mace and Lande (1991) reported that the genetic effective population size is typically 20–50% of the actual population size.

Table 1. 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 500, a 1:1 sex ratio, and an $N_e/N_g$ ratio of 0.30, an estimated $N_g$ of 1,667 was derived as the estimated number of adult humpback chub necessary to maintain a genetic effective population size. This approach does not imply that existing populations should be allowed to decrease to this level; the estimate of 1,667 is used as a gauge to evaluate genetic viability of isolated populations. The extent of genetic linkage among humpback chub populations is not known with certainty. Although the lack of genetic differentiation among the six populations suggests panmixis (Dowling and DeMarais 1993), mark-recapture studies show only limited exchange of fish. Tag recaptures document movement between Black Rocks and Westwater Canyon, and among the LCR and four downstream aggregations in Grand Canyon, but these studies have not shown exchange of fish with or among Cataract Canyon, Yampa Canyon, or Desolation/Gray Canyons. Exchange of individuals among these populations may occur over several decades at a sufficient rate to nullify significant genetic differentiation. Mark-recapture studies in the Black Rocks/Westwater Canyon populations and the Grand Canyon population have shown no exchange of individuals outside of these "core populations", making them appear to be genetically isolated for the past two decades of study. Based on this assumption of short-term genetic isolation, existing numbers of 2,900–6,500 adults and

2,000–4,700 adults, respectively, exceed an $N_g$ of 1,667 and indicate good genetic viability for these core populations. Although the three smaller populations (i.e., Cataract Canyon, Yampa Canyon, Desolation/Gray Canyons) are currently estimated at fewer than 1,667 adults, they are, nevertheless, important to species viability as redundant populations. Better estimates of population size may show that the Desolation/Gray Canyons population is larger than 1,500 adults; this would provide a third genetically viable core population.

### *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 2,100 adults was derived by adding 24% to the $N_g$ of 1,667 to account for an estimate of the average annual mortality of adult humpback chub (1,667 x 1.24 = 2,067 or about 2,100; Box 4; Valdez and Ryel 1995, 1997). 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).

**<u>Box 4. Computation of Minimum Viable Population (MVP)</u>**

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

where: $N_e$ = genetic effective population size, 500

$N_e/N_g$ = proportion of adults contributing genes to next generation; ~0.30 for most fish

therefore: $N_g = 500/0.30$

$N_g = 1,667$

hence: MVP = 1,667 x 1.24 = 2,067 (rounded to 2,100)

where: 1.24 compensates for annual adult mortality of 24%

At least two core populations of humpback chub were identified with numbers of adults that approach or exceed the MVP of 2,100 (i.e., Black Rocks/Westwater Canyon and Grand Canyon). A third core population may exist in Desolation/Gray Canyons, but reliable population estimates are not currently available for that population. These cores contain sufficient numbers of adults to ensure genetic and demographic viability, and subadult numbers show that reproduction and recruitment provide self-sustainability (see Appendix A). These core populations become the central basis for recovery because they provide secure population centers from which dispersal can occur and provide redundancy from catastrophes that may affect one or more populations.

# 4.0 THREATS TO HUMPBACK CHUB BY LISTING FACTOR

The humpback chub was designated as an endangered species prior to enactment of the ESA, and a formal listing package identifying threats was not assembled. Construction and operation of mainstem dams, nonnative fish species, and local eradication of native minnows and suckers in advance of new human-made reservoirs in the early 1960's were recognized as early threats (Miller 1961; Holden 1991), and the species was included in the United States List of Endangered Native Fish and Wildlife on June 4, 1973 (38 FR No. 106). A description of Threatened Wildlife of the United States compiled by the Office of Endangered Species and International Activities (U.S. Bureau of Sports Fisheries and Wildlife 1973) identified the reasons for decline of the humpback chub as *"unknown"*. Although habitat losses were recognized, the threats were poorly understood, and distribution and abundance of the species were not well known.

Threats to the species were presented in the Recovery Plan (U.S. Fish and Wildlife Service 1990a), which stated that:

> *"The decline of the humpback chub may be due to a combination of factors such as: stream alteration (dams, irrigation, dewatering, and channelization); competition with and predation by introduced, nonnative fish species; hybridization with other Gila; and other factors."*

In addition to stream alteration, nonnative fish species, and hybridization, the Recovery Plan identified pesticides, pollutants, and parasitism as other factors that have contributed to the decline of the species. Hence, the primary threats to humpback chub populations are streamflow regulation and habitat modification (including cold-water dam releases and habitat loss), competition with and predation by nonnative fish species, parasitism, hybridization with other native *Gila*, and pesticides and pollutants (Box 5). These threats are associated with the five listing factors (see section 2.1), and a

**Box 5. Primary Threats To Humpback Chub**

- Streamflow regulation.
- Habitat modification.
- Predation by nonnative fish species.
- Parasitism.
- Hybridization with other native *Gila* ssp.
- Pesticides and pollutants.

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.

## 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 humpback chub populations. 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 immediately upstream of the Black Rocks and Westwater Canyon humpback chub populations have decreased by 29–38% (Van Steeter and Pitlick 1998). Flows of the Green River at Jensen, Utah, upstream of the Desolation/Gray Canyons population 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). The combined flow regulation of the Colorado and Green rivers influences habitat conditions in Cataract Canyon, although to a lesser degree because of ameliorating downstream effects and tributary inflows. Habitat of the Yampa River has not been as extensively affected by streamflow regulation as in other rivers of the basin (Modde and Smith 1995; Modde et al. 1999; U.S. Fish and Wildlife Service 2000). In the lower basin, flow of the Colorado River in occupied habitat in Grand Canyon is regulated by Glen Canyon Dam, except for the influence of small tributary inflows. Spring peak flows have been reduced by about 80%, and summer–winter base flows have been increased by about 30% (U.S. Department of the Interior 1995). Regulation of the LCR, the largest tributary of the Colorado River in Grand Canyon, has eliminated surface flow to occupied habitat at all times except during spring runoff and local rainstorms. Streamflow to the lower 14.9 km of habitat occupied by the humpback chub population is sustained by a series of springs in the lower LCR (i.e., Blue Springs) and by high spring runoff and periodic rain-induced floods (see SWCA 2000 for a description of hydrology of the LCR).

Reservoir inundation, cold-water releases from dams, streamflow alteration, changes in channel geomorphology, and modification of sediment transport have impacted habitat of the native Colorado River fishes, including the humpback chub. Since 1905, numerous human-made dams have been constructed throughout the Colorado River Basin, fragmenting habitat and blocking fish passage (maintaining connection within and among populations is important to allow gene flow for maximum genetic diversity). These dams have reduced river flow, altered temperature and flow regimes, trapped sediments and nutrients, changed water quality, and created reservoirs and a continuous source of nonnative fishes (Maddux et al. 1993). In the lower basin, 14 major dams have restricted fish movement 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 segregates the upper and lower recovery unit populations.

Dams were considered a major threat to the humpback chub at the time of listing; however, construction of new dams affecting occupied habitat ceased nearly 4 decades ago. The ongoing threat is no longer new dam construction but the effects linked to the presence and operation of existing dams. Construction of mainstem dams during the early 1960's directly impacted about 102 km of humpback chub habitat by reservoir inundation and about 739 km indirectly through streamflow regulation (Chart and Lentsch 1999, 2000; Van Steeter and Pitlick 1998) and cold-water hypolimnetic releases (Kaeding and Zimmerman 1983; Valdez and Ryel 1997). Humpback chub have been reduced in distribution or extirpated from three areas where they historically occurred, including Flaming Gorge Canyon (Gaufin et al. 1960), Narrow and Lower Cataract canyons (Valdez 1990; Valdez and Williams 1993), and portions of Marble and Grand canyons (Miller 1944; Holden and Stalnaker 1975b; Valdez and Ryel 1995). Habitat lost to inundation by reservoirs includes 18 km in lower Grand Canyon by Lake Mead; 52 km in Narrow and Lower Cataract canyons by Lake Powell; and 32 km below Hideout Canyon by Flaming Gorge Reservoir. Abundance and distribution were possibly also reduced in Whirlpool and Split Mountain canyons by either a pre-dam fish eradication rotenone program (Holden 1991) or by cold releases from Flaming Gorge Dam. Investigators found humpback chub in these canyons during and shortly after closure of Flaming Gorge Dam (Vanicek et al. 1970; Holden and Stalnaker 1975b), but more recent surveys have reported few individuals. Clear, cold-water releases have modified the food supply and precluded mainstem spawning in the Colorado River in Marble and Grand canyons (potential habitat of 403 km) below Glen Canyon Dam. Cold-water temperatures may also reduce swimming ability of young native fish and increase their susceptibility to predation by cold-water fishes, such as trout (Valdez and Ryel 1995).

Changes in channel geomorphology of habitat occupied by humpback chub is not extensive because most habitat occurs in rocky canyon-confined reaches with low susceptibility to geomorphic modification. However, sediment-transport mechanisms through occupied habitat, particularly downstream of dams (Schmidt and Rubin 1995), have been altered substantially, resulting in overall reduction of sediment loads through occupied habitat. This sediment reduction has altered ecological riverine processes, including reduction in organic loads as sources of food production; losses of sand beaches, backwaters, and habitat diversity; and decreased water turbidity as a cover element from sight predators such as brown trout (*Salmo trutta*) and rainbow trout (Marsh and Douglas 1997; Valdez and Ryel 1997). Mean annual sediment discharge of the Green River at Green River, Utah, decreased by 48% following completion of Flaming Gorge Dam in 1962 (Andrews 1986). Sediment load in the Colorado River through Grand Canyon has been reduced by about 99% by entrainment in Lake Powell reservoir. This has resulted in a reduction in sediment supply and loss of sand beaches that provide backwater habitats for young humpback chub (U.S. Department of the Interior 1995). It is anticipated that implementation of recommended flows, discussed below, will provide adequate sediment transport and distribution to restore some of the natural riverine functions.

Maintenance of streamflow is important to the ecological integrity of large western rivers (Tyus and Karp 1989; 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).

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 1995; Holden 1999; Modde et al. 1999; 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 humpback chub mimic the natural hydrograph and include spring peak flows and summer–winter base flows. Adults utilize eddies and sheltered shoreline habitats maintained by high spring flows (see Appendix A for details on habitat requirements). These high spring flows maintain channel and habitat diversity, flush sediments from spawning areas, rejuvenate food production, and form gravel and cobble deposits used for spawning (McAda 2000; Muth et al. 2000). Spawning occurs on the descending limb of the spring hydrograph at water temperatures typically between 16 and 22°C. Increased production and recruitment have been correlated with moderate-to-high water years (Valdez and Ryel 1995; Gorman and Stone 1999). Young typically use low-velocity shoreline habitats, including eddies and backwaters, that are more prevalent under base-flow conditions. High spring flows also disadvantage nonnative fishes (McAda and Kaeding 1989; Valdez 1990; Hoffnagle et al. 1999), reducing predation and competition. Low base flows also increase shoreline food production.

Flow recommendations have been developed that specifically consider flow-habitat relationships in habitats occupied by humpback chub in the upper basin (see section 3.1.2) including Black Rocks and Westwater Canyon (McAda 2000); Whirlpool, Split Mountain, and Desolation/Gray canyons (Muth et al. 2000); Yampa Canyon (Modde and Smith 1995; Modde et al. 1999; U.S. Fish and Wildlife Service 2000); and Cataract Canyon (McAda 2000; Muth et al. 2000). 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). In addition to these upper basin flow recommendations, an Environmental Impact Statement (EIS) in 1995, with a Record of Decision in 1996, established releases from Glen Canyon Dam that will be evaluated through adaptative management to protect resources of the Colorado River through Grand Canyon (U.S. Department of the Interior 1995). These Modified Low Fluctuating Flows (MLFF) reduced daily fluctuations in river flow from peak power plant releases, and allow for high spring releases to restore some aspects of the natural hydrograph. However, the 1994 Biological Opinion on the operation of Glen Canyon Dam (U.S. Fish and Wildlife Service 1994) determined that the new release regime of MLFF "*...is likely to jeopardize the continued existence of the humpback chub...*".

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

Overutilization of humpback chub 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.

Humpback chub 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 in Black Rocks and Westwater Canyon (personal communication, E. Wick). All angler access points near occupied habitat are posted with signs advising anglers to release any endangered fish unharmed.

Collection of humpback chub 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 humpback chub 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 humpback chub in the upper basin (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. However, in the lower basin, Meretsky et al. (2000) hypothesized that an observed decline in condition of adult humpback chub in Grand Canyon was a result of recent infestation by the internal Asian tapeworm (*Bothriocephalus acheilognathi*). During 1996–1997, the Asian tapeworm occurred in 31.6–84.2% of humpback chub examined in the LCR and 8.8–26.7% in the Colorado River (Hoffnagle et al. 2000). The Asian tapeworm is a recent invader of the LCR; it was first reported from Grand Canyon in 1990 (Clarkson et al. 1997;

Brouder and Hoffnagle 1997). It is considered a dangerous parasite capable of killing its hosts and may be a potential population-suppressing agent, although detrimental effects to humpback chub populations have not been documented. The Asian tapeworm has not been reported from upper basin humpback chub populations.

### *4.3.2 Nonnative fishes*

The threat of predation by nonnative fishes on humpback chub has been recognized in three populations. In Grand Canyon, brown trout, channel catfish (*Ictalurus punctatus*), black bullhead (*Ameiurus melas*), and rainbow trout have been identified as principal predators of juvenile humpback chub, with consumption estimates that suggest loss of complete year classes to predation (Marsh and Douglas 1997; Valdez and Ryel 1997). Marsh and Douglas (1997) documented predation on humpback chub in the LCR by rainbow trout, channel catfish, and black bullhead. Valdez and Ryel (1997) identified brown trout, rainbow trout, and channel catfish as known predators of humpback chub in the mainstem Colorado River in Grand Canyon, and suggested that common carp (*Cyprinus carpio*) could be a significant predator of incubating humpback chub eggs in the LCR. In the upper basin, Chart and Lentsch (2000) identified channel catfish as the principal predator of humpback chub in Desolation/Gray Canyons. In Yampa Canyon, the UCRRP identified channel catfish as the principal predator and is pursuing development and implementation of a control program.

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 native fishes. 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. 1999), and a Science Plan is being developed for implementation of nonnative fish removal starting in 2003 (GCMRC 2002).

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 reaches of the mainstem Colorado River through Grand Canyon and in the LCR.

Annual flooding of the river can inundate riverside ponds potentially containing large numbers of green sunfish (*Lepomis cyanellus*), black bullhead, largemouth bass (*Micropterus salmoides*), 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.

Additionally, both upper basin and lower basin States have removed bag limits on nonnative fishes in designated critical habitat of humpback chub. The State of Colorado has removed bag 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. In the lower basin, the Arizona Game and Fish Commission, in January, 1998, approved fishing regulation changes for several State waters designed to reduce numbers of nonnative fishes, including the following for humpback chub occupied habitat in the Colorado River through Grand Canyon:

> *"Unlimited harvest of trout, channel catfish and striped bass from the Colorado River in the Grand Canyon from Separation Canyon (above Lake Mead) to Marble Canyon Bridge. All fish must be kept when caught."*

The regulation was modified before approval to state that *"...fish may be kept when caught."* Existing regulations in Grand Canyon also prohibit use of live fish as bait. Occasional discovery of bait minnows, such as golden shiner (*Notemigonus crysoleucas*; particularly at Lee Ferry), suggests that illegal use of live bait fish continues, albeit at low levels.

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 [*Pimephales promelas*], red shiner [*Cyprinella lutrensis*], sand shiner [*Notropis stramineus*], 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). A strong year class of humpback chub in Grand Canyon in 1993 followed high early spring-runoff flows from the Little Colorado River, and was attributed to cleansing of spawning gravels and short-term reduction in nonnative fishes (Gorman 1994). Strong year classes following high runoff years are also seen in other Colorado River species (e.g., Colorado pikeminnow). 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 Yampa Canyon, Desolation/Gray Canyons, and Grand Canyon. 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 humpback chub 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 humpback chub 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 humpback chub 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 humpback chub 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. 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 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, humpback chub 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 humpback chub 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 humpback chub 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 humpback chub 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.

Hazardous-materials spills are identified as a threat to humpback chub, particularly populations in Black Rocks, Westwater Canyon, Yampa Canyon, and the LCR. Although the States of Colorado, Utah, and Arizona, where these populations occur, have state-wide hazardous-materials plans, these may not be adequate to provide protection against spills into the river at or near these locations. Research into the adequacy of these plans is identified as a recovery element. Hazardous-materials spills are regulated by the Hazardous Materials and Waste Management Division of the Colorado Department of Public Health and Environment; the Hazardous Waste Branch of the Utah Department of Environmental Quality; and the Hazardous Waste Section of the Arizona Department of Environmental Quality.

The need for conservation plans and agreements was identified to provide reasonable assurances that recovered humpback chub 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*

Humpback chub, bonytail, and roundtail chub (*Gila robusta*) are sympatric Colorado River mainstem species with substantial evidence of introgressive hybridization (Dowling and DeMarais 1993). Intraspecific and interspecific morphological variation can be extensive where these three species coexist. This apparent introgressive hybridization has resulted in high phenotypic plasticity with morphologic intergrades present in all sympatric populations of Colorado River *Gila* (Holden and Stalnaker 1970; Smith et al. 1979; Valdez and Clemmer 1982; Kaeding et al. 1990; Wick et al. 1991; McElroy and Douglas 1995; Douglas et al. 1998). These intergrades suggest, to some, extensive hybridization with possible concomitant loss of genetic diversity and evolutionary adaptive traits (Valdez and Clemmer 1982; Rosenfeld and Wilkinson 1989). Others believe that introgressive hybridization is part of the common evolutionary history of the Colorado River *Gila*, resulting in high phenotypic plasticity and adaptability to the rigorous physical habitats present in the Colorado River Basin (Dowling and DeMarais 1993). Evidence of intergrades was reported prior to extensive human alterations to the basin (Miller 1946).

Proportions of humpback chub, roundtail chub, bonytail, and intergrades from each of the six populations of humpback chub are shown in Table A-1 (see section A.3). Proportions of these phenotypes in Black Rocks and Westwater Canyon vary primarily because of increased invasion of these canyon areas by roundtail chub during low water years (Chart and Lentsch 1999). Despite this variation, overall average proportions of humpback chub:roundtail chub:intergrades for Black Rocks and Westwater Canyon are similar as 48:45:8 and 44:45:12, respectively. Average proportions in Desolation/Gray Canyons of 19:7:74 show the highest proportions of intergrades of any population of humpback chub. Proportions in the LCR and Colorado River in Grand Canyon are 100% humpback chub because the known genotype is primarily of this form (Dowling and DeMarais 1993), and recent samples show little evidence of other phenotypes in this population (McElroy and Douglas 1995). Proportions of 46:23:13:18 in Cataract Canyon include bonytail and indicate a large diverse complex of *Gila* associated with this population (McElroy and Douglas 1995). The proportion of 14:86:0 in Yampa Canyon shows a large percentage of roundtail chub relative to humpback chub and little or no intergradation between these forms.

Proportions of humpback chub to roundtail chub and catch rates recorded by investigators in Black Rocks (Kaeding et al. 1990) and Westwater Canyon (Chart and Lentsch 2000) reveal a greater proportion of roundtail chub in these areas in years of low flow; it is hypothesized that lower velocities and less turbulence in low water years allow roundtail chub to invade canyon regions not normally inhabited by this species. Increased sympatry of these species potentially increases the chances for hybridization; hybridization has been demonstrated in a hatchery among all three *Gila* species. Hence, it is necessary to provide flow regimes that reflect inter-annual variability in hydrologic conditions (e.g., wet, average, and dry water years) in order to maintain natural proportions of *Gila* species and intergrades.

### *4.5.2 Pesticides and pollutants*

The potential role of pesticides and pollutants in suppressing populations of *Gila* were discussed by Wick et al. (1981). Over 16% of young roundtail chub from the Yampa and Colorado rivers in 1981 showed spinal deformities (i.e., lordosis), hypothesized to be possibly related to high pesticide levels from local agricultural applications (Haynes and Muth 1981). Other pollutants in the system include petroleum products, heavy metals (e.g., mercury, lead, zinc, copper), nonmetalics (i.e., selenium), and radionucleides. Although these elements are concentrated in some regions of the basin, no tissue analyses have been conducted for humpback chub to determine current levels of bioaccumulation. Selenium has been identified as a potential problem for razorback sucker and Colorado pikeminnow (Osmundson et al. 2000a).

Potential spills of hazardous materials threaten some populations of humpback chub (Table 2). The Denver and Rio Grande Western railroad tracks parallel the Colorado River at Black Rocks and upper Westwater Canyon with the risk of derailment and spills of materials into the river, although no known derailments have occurred in these areas. The susceptibility of these humpback chub populations to toxic substances is illustrated by a large, but unquantified, fish kill in Westwater Canyon in the 1980's as a result of a large ash flow following a range wildfire high in the watershed (personal communication, J. Cresto, U.S. Bureau of Land Management). Ash and large amounts of sediment washed down Westwater Creek during a sudden thunderstorm. A similar threat from petroleum products exists for the population in the LCR with the risk of trucks overturning and spilling their loads while crossing the Highway 89 bridges at Cameron, Arizona. Shipping traffic is allowed to cross on two bridges near Cameron, which are about 60 km upstream of habitat occupied by humpback chub in the lower LCR. The potential for spills of petroleum products also exists in the upper basin. 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 humpback chub that is extremely limited in distribution within canyon reaches. Quick response may, therefore, be inadequate to protect the species and preventive measures must be incorporated into these plans. These preventive measures may include reduced speed of railway traffic near occupied habitats, such as Black Rocks and Westwater Canyon; 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, such as at the Cameron bridges. 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.

Table 2. Potential, existing, or past threats from pesticides and pollutants to six populations of humpback chub.

| Population | Threats From Pesticides and Pollutants |
|---|---|
| Upper Basin Recovery Unit | |
| Black Rocks | • Denver and Rio Grande Western railroad tracks parallel Colorado River at Black Rocks with risk of derailment and spills into the river |
| Westwater Canyon | • Denver and Rio Grande Western railroad tracks parallel Colorado River at upper Westwater Canyon and cross Westwater Creek with risk of derailment and spills into the river |
| Yampa Canyon | • Numerous petroleum product pipelines cross or parallel the Yampa River; most pipelines lack safety cutoff valves<br>• A high incidence of spinal deformity has been reported in *Gila* spp., believed to be caused by agricultural pesticides |
| Desolation/Gray Canyons | • No identified threat |
| Cataract Canyon | • No identified threat |
| Lower Basin Recovery Unit | |
| Grand Canyon<br>—Little Colorado River | • Risk of trucks overturning and spilling their loads into the LCR while crossing Highway 89 bridges at Cameron, 55–65 km upstream of occupied habitat |
| Grand Canyon<br>—Colorado River | • Little apparent risk of spills except from materials coming down the LCR |

# 5.0 RECOVERY GOALS

The following are site-specific management actions and objective, measurable recovery criteria for the humpback chub 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 Lake Mead National Recreation Area). The humpback chub 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 humpback chub. 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.

## 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 specify no net loss in each of the six existing populations, based on requirements of no significant decline in numbers of adults for each population and recruitment equal to or exceeding adult mortality, and genetically and demographically viable, self-sustaining core populations.

Wild populations of humpback chub have been studied since the 1960's, and population dynamics and responses to management actions have been evaluated since the early 1980's. 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. 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 humpback chub, 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 humpback chub, the age of attaining sexual maturity is 4 years and the adult survival rate is 0.76 (d=1-0.76); hence, generation time is 4 + [1/(1-0.76)] = 4 + 4 = 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 six extant humpback chub populations to downlist, and at least two more estimates are needed to delist. Point estimates should be made in each of 2–3 consecutive years with 1–2 years between blocks of estimates. In order to ensure no net loss in each population, the trend in adult (age 4+; ≥200 mm TL; see section A.9) 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 (150–199 mm TL; see section A.9) naturally produced fish in each population must equal or exceed mean annual adult mortality (i.e., ≥24%). This criterion requires that each population is reproducing, recruiting, and self-sustaining. To meet the requirement of genetically and demographically viable, self-sustaining, core populations, each point estimate for each core population must exceed 2,100 adults (MVP; see section 3.3.2); two core populations are required for downlisting and three for delisting. In addition to the demographic criteria, adequate habitat and sufficient range are required to support recovered populations. Recovery goals require 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.

Each of the six threats identified in section 4.0 (i.e., streamflow regulation, habitat modification, competition with and predation by nonnative fishes, parasitism, hybridization, 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, Adaptive Management Program Strategic Plan of the GCDAMP, and in annual work plans of the 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 humpback chub. 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 document of the UCRRP (U.S. Department of the Interior 1987), under this program legal protection of flows referenced in these recovery goals for upper basin rivers 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 humpback chub 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.

### *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 (which include an acceptable level of uncertainty) and ensuring the viability of the species beyond delisting. It is expected that research, management, and monitoring activities directed by the UCRRP, GCDAMP, and MSCP will fill information gaps and considerably narrow, if not eliminate, many of the uncertainties that affect recovery criteria. Additional data and improved understanding of humpback chub biology may 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:

- Carrying Capacity. The carrying capacity for humpback chub populations is unknown. Humpback chub presently occupy most, if not all, of the available suitable habitat that remains in the Colorado River Basin, and the potential for establishing additional stocks is probably low. Populations that presently appear relatively stable (i.e., Black Rocks, Westwater Canyon, Grand Canyon) may not have the capacity to increase substantially and may be at or near functional carrying capacity. However, it may be possible for populations to expand their range naturally if resource limitations are minimized or removed.
- Genetic Viability. Although determination of genetic effective population size ($N_e$) was based on principles in conservation genetics (i.e., "50/500 rule"), genetic information on humpback chub was insufficient to derive a species-specific value

of $N_e$ and a ratio of $N_e/N_g$. In addition, the extent of genetic linkage among humpback chub populations is not known with certainty.

- Flow and Temperature Recommendations. Flow and temperature recommendations have been developed that specifically consider flow-habitat relationships in habitats occupied by humpback chub. 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 humpback chub. 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 humpback chub 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.
- Nonnative Fish Response. 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.
- Efficacy of Monitoring Programs. The precision and reliability of long-term monitoring programs to accurately measure the response of humpback chub populations to management actions is an uncertainty. Mark-recapture population estimates 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.
- Response to Management Actions. Management actions, such as regulation of escapement of nonnative fishes, control of parasites, control of nonnative fishes, and minimization of the risk of hazardous-materials spills, may vary in their effectiveness to benefit humpback chub. 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 humpback chub 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 humpback chub populations in the upper Colorado, Green, and Yampa rivers (see section 4.1 for discussion of existing flow recommendations to benefit the endangered fishes and for discussion of humpback chub flow-habitat requirements; see Appendix A for a synopsis of humpback chub life history).

Task A-1.2.—Provide flow regimes (as determined under Task A-1.1) that are necessary for all life stages of humpback chub to support recovered populations in Black Rocks, Westwater Canyon, Yampa Canyon, Desolation/Gray Canyons, and Cataract Canyon.

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

Management Action B-1.—Protect humpback chub 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 humpback chub 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 for humpback chub 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 humpback chub populations.

Task C-1.1.—Reevaluate and, if necessary, identify actions to minimize adverse effects of diseases and parasites on humpback chub populations; not currently identified as an existing threat in the upper basin (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 humpback chub 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 to minimize negative interactions between nonnative fishes and humpback chub (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 humpback chub.

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

Task C-3.1.—Develop channel catfish control programs in Yampa Canyon and Desolation/Gray Canyons to identify levels of control that will minimize predation on humpback chub (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 channel catfish control in Yampa Canyon and Desolation/Gray Canyons.

#### 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 humpback chub 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 humpback chub to support recovered populations.

Management Action D-2.—Provide for the long-term management and protection of humpback chub 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 humpback chub 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 humpback chub, regulation and/or control of nonnative fishes, minimization of the risk of hazardous-materials spills, minimization of risks of parasites, 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 humpback chub 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 among *Gila* species in river reaches occupied by humpback chub.

Task E-1.1.—Provide flow regimes that reflect inter-annual variability in hydrologic conditions in order to maintain natural proportions of *Gila* species and intergrades in Black Rocks, Westwater Canyon, Yampa Canyon, Desolation/Gray Canyons, and Cataract Canyon (see sections 4.5.1 and A.3 for discussion of hybridization).

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 humpback chub 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 measures to minimize the risk of hazardous-materials spills in Black Rocks and Westwater Canyon from transport of materials along the adjacent railway.

Task E-2.4.—Implement measures (as determined under Task E-2.3) to minimize the risk of hazardous-materials spills in Black Rocks and Westwater Canyon from transport of materials along the adjacent railway.

Task E-2.5.—Identify 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-2.6.—Install emergency shut-off valves (as determined under Task E-2.5) on problematic petroleum-product pipelines within the 100-year floodplain of critical habitat.

### *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.—Investigate the role of the mainstem Colorado River in maintaining the Grand Canyon humpback chub population and provide appropriate habitats in the mainstem as necessary for recovery.

Task A-1.1.—Identify life stages and habitats of humpback chub in the mainstem Colorado River and determine the relationship between individuals in the mainstem Colorado River and Little Colorado River.

Task A-1.2.—Provide appropriate habitats for humpback chub in the mainstem Colorado River (as determined necessary under Task A-1.1).

Management Action A-2.—Provide flows necessary for all life stages of humpback chub to support a recovered Grand Canyon population, based on demographic criteria.

Task A-2.1.— As determined necessary and feasible, continue to operate Glen Canyon Dam water releases under adaptive management to benefit humpback chub in the mainstem Colorado River through Grand Canyon (see section 4.1 for discussion of existing releases from Glen Canyon Dam and for discussion of humpback chub flow-habitat requirements; see Appendix A for a synopsis of humpback chub life history).

Task A-2.2.—Identify, implement, evaluate, and revise (as necessary through adaptive management) a flow regime in the Little Colorado River to benefit humpback chub.

Task A-2.3.—Provide flow regimes (as determined under Tasks A-2.1 and A-2.2) that are necessary for all life stages of humpback chub to support a recovered Grand Canyon population.

Management Action A-3.—Investigate the anticipated effects of and options for providing warmer water temperatures in the mainstem Colorado River through Grand Canyon that would allow for range expansion of the Grand Canyon humpback chub population and provide appropriate water temperatures if determined feasible and necessary for recovery.

Task A-3.1.—Determine the effects and feasibility of a temperature control device for Glen Canyon Dam under the Glen Canyon Dam Adaptive Management Program (U.S. Bureau of Reclamation 1999) to increase water temperatures in the mainstem Colorado River through Grand Canyon that would allow for range expansion of humpback chub.

Task A-3.2.—Implement a temperature control device for Glen Canyon Dam if determined feasible and necessary for recovery of humpback chub.

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

Management Action B-1.—Protect humpback chub 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 humpback chub 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 for humpback chub populations 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.—Control Asian tapeworm as needed.

Task C-1.1.—Develop an Asian tapeworm control program in the Little Colorado River to identify the levels of control that will minimize the negative effects of parasitism on the humpback chub population (see sections 4.3.1 and A.12 for discussion of diseases and parasites).

Task C-1.2.—Implement identified levels (as determined under Task C-1.1) of Asian tapeworm control in the Little Colorado River.

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 and to minimize escapement of nonnative fish species into the Colorado River and its tributaries through Grand Canyon to minimize negative interactions between nonnative fishes and humpback chub (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 Colorado River and its tributaries through Grand Canyon to minimize negative interactions between nonnative fishes and humpback chub.

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

Task C-3.1.—Develop rainbow trout, channel catfish, black bullhead, and common carp control programs in the Little Colorado River to identify levels of control that will minimize predation on humpback chub (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 rainbow trout, channel catfish, black bullhead, and common carp control in the Little Colorado River.

Task C-3.3.—Develop brown trout and rainbow trout control programs in the Colorado River through Grand Canyon to identify levels of control that will minimize predation on humpback chub.

Task C-3.4.—Implement identified levels (as determined under Task C-3.3) of brown trout and rainbow trout control in the Colorado River through Grand Canyon.

### 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 humpback chub to support a recovered Grand Canyon population, based on demographic criteria.

Task D-1.1.—Determine mechanisms for legal protection of adequate habitat in the mainstem Colorado River through Grand Canyon and the Little Colorado River 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 in the mainstem Colorado River and the Little Colorado River (as determined under Task D-1.1) that are necessary to provide adequate habitat and sufficient range for all life stages of humpback chub to support a recovered Grand Canyon population.

Management Action D-2.—Provide for the long-term management and protection of humpback chub 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 humpback chub 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 humpback chub, regulation and/or control of nonnative fishes, minimization of the risk of hazardous-materials spills, minimization of risks of parasites, 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 humpback chub populations will be maintained.

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

Management Action E-1.—Minimize the risk of hazardous-materials spills in critical habitat.

Task E-1.1.—Review and recommend modifications to State and Federal hazardous-materials spills emergency-response plans to ensure adequate protection for humpback chub 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-1.2.—Implement State and Federal emergency-response plans that contain the necessary preventive measures (as determined under Task E-1.1) for hazardous-materials spills.

Task E-1.3.—Identify measures to minimize the risk of hazardous-materials spills from transport of materials along U.S. Highway 89 at and near the two Cameron bridges spanning the Little Colorado River.

Task E-1.4.—Implement measures (as determined under Task E-1.3) to minimize risk of hazardous-materials spills from transport of materials along U.S. Highway 89 at and near the two Cameron bridges spanning the Little Colorado River.

## 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

1. Each of the five self-sustaining populations 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+; ≥200 mm TL) point estimates does not decline significantly, and

    b. mean estimated recruitment of age-3 (150–199 mm TL) naturally produced fish equals or exceeds mean annual adult mortality, and

2. One of the five populations (e.g., Black Rocks/Westwater Canyon or Desolation/Grey canyons) is maintained as a core population such that each point estimate exceeds 2,100 adults (Note: 2,100 is the estimated MVP number; see section 3.3.2).

**5.3.1.1.2 Lower basin recovery unit**

1. The Grand Canyon population is maintained as a core over a 5-year period, starting with the first point estimate acceptable to the Service, such that:

    a. the trend in adult (age 4+; ≥200 mm TL) point estimates does not decline significantly, and

    b. mean estimated recruitment of age-3 (150–199 mm TL) naturally produced fish equals or exceeds mean annual adult mortality, and

    c. each core population point estimate exceeds 2,100 adults (MVP).

**5.3.1.2 Recovery factor criteria for downlisting (recovery factor criteria 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 humpback chub populations in the upper Colorado, Green, and Yampa rivers 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) is available to maintain self-sustaining populations, as reflected by downlisting demographic criteria in section 5.3.1.1.1.

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

2. Overutilization of humpback chub 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.**

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

4. Procedures developed, implemented, evaluated, and revised for stocking nonnative fish species in the Upper Colorado River Basin to minimize negative interactions between nonnative fishes and humpback chub (Task C-2.1).

5. Channel catfish control programs developed and implemented to identify levels of control that will minimize predation on humpback chub in Yampa Canyon and Desolation/Gray Canyons (Task C-3.1).

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

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

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

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

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

9. Measures identified to minimize the risk of hazardous-materials spills in Black Rocks and Westwater Canyon from transport of materials along the adjacent railway (Tasks E-2.3).

10. 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-2.5).

#### 5.3.1.2.2 Lower basin recovery unit

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

1. Life stages and habitats of humpback chub in the mainstem Colorado River identified and the relationship between individuals in the mainstem and the Little Colorado River determined (Task A-1.1).

2. Operations of Glen Canyon Dam to benefit humpback chub in the Colorado River through Grand Canyon continued (Task A-2.1) and a flow regime to benefit humpback chub in the Little Colorado River identified, implemented, evaluated, and revised (Task A-2.2), such that:

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

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

3. Effects and feasibility of a temperature control device for Glen Canyon Dam to increase water temperatures in the mainstem Colorado River through Grand Canyon that would allow for range expansion of humpback chub determined (Task A-3.1).

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

4. Overutilization of humpback chub 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. Asian tapeworm control program developed and implemented in the Little Colorado River to identify levels of control that will minimize the negative effects of parasitism on the humpback chub population (Task C-1.1).

6. Procedures developed, implemented, evaluated, and revised for stocking and to minimize escapement of nonnative fish species into the Colorado River and its tributaries through Grand Canyon to minimize negative interactions between nonnative fishes and humpback chub (Task C-2.1).

7. Rainbow trout, channel catfish, black bullhead, and common carp control programs developed and implemented to identify levels of control that will minimize predation on humpback chub in the Little Colorado River (Task C-3.1).

8. Brown trout and rainbow trout control programs developed and implemented to identify levels of control that will minimize predation on humpback chub in the Colorado River through Grand Canyon (Task C-3.3).

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

9. Mechanisms determined for legal protection of adequate habitat in the mainstem Colorado River through Grand Canyon and the Little Colorado River (Task D-1.1).

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

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

11. State and Federal hazardous-materials spills emergency-response plans reviewed and modified to ensure adequate protection for humpback chub populations from hazardous-materials spills (Task E-1.1).

12. Measures identified to minimize the risk of hazardous-materials spills from transport of materials along U.S. Highway 89 at and near the two Cameron bridges spanning the Little Colorado River (Task E-1.3).

### *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

1. Each of the five self-sustaining populations 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+; ≥200 mm TL) point estimates does not decline significantly, and

   b. mean estimated recruitment of age-3 (150–199 mm TL) naturally produced fish equals or exceeds mean annual adult mortality, and

2. Two of the five populations (e.g., Black Rocks/Westwater Canyon and Desolation/Grey canyons) are maintained as core populations such that each point estimate exceeds 2,100 adults (MVP).

##### 5.3.2.1.2 Lower basin recovery unit

1. The Grand Canyon population is maintained as a core 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+; ≥200 mm TL) point estimates does not decline significantly, and

   b. mean estimated recruitment of age-3 (150–199 mm TL) naturally produced fish equals or exceeds mean annual adult mortality, and

   c. each core population point estimate exceeds 2,100 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 humpback chub to support recovered populations in Black Rocks, Westwater Canyon, Yampa Canyon, Desolation/Gray Canyons, and Cataract Canyon (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 is 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) is available to maintain self-sustaining populations, as reflected by delisting demographic criteria in section 5.3.2.1.1.

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

2. Adequate protection of humpback chub populations from overutilization for commercial, recreational, scientific, or educational purposes attained (Task B-1.2).

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

3. Adequate protection of humpback chub populations from deleterious diseases and parasites attained (Task C-1.2).

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

5. Identified levels of channel catfish control to minimize predation on humpback chub attained in Yampa Canyon and Desolation/Gray Canyons (Task C-3.2).

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

6. Habitat necessary to provide adequate habitat and sufficient range for all life stages of humpback chub to support recovered populations in Black Rocks, Westwater Canyon, Yampa Canyon, Desolation/Gray Canyons, and Cataract Canyon is legally protected in perpetuity (Task D-1.2).

7. 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 humpback chub populations will be maintained (Task D-2.2).

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

8. Flow regimes provided that reflect inter-annual variability in hydrologic conditions in order to maintain natural proportions of *Gila* species and intergrades in Black Rocks, Westwater Canyon, Yampa Canyon, Desolation/Gray Canyons, and Cataract Canyon (Task E-1.1).

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

10. Measures finalized and implemented to minimize the risk of hazardous-materials spills in Black Rocks and Westwater Canyon from transport of materials along the adjacent railway (Task E-2.4).

11. Emergency shut-off valves installed on all problematic petroleum-product pipelines within the 100-year floodplain of critical habitat (Task E-2.6).

#### 5.3.2.2.2 Lower basin recovery unit

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

1. Appropriate habitats for humpback chub in the mainstem Colorado River provided (Task A-1.2).

2. Flow regimes provided in the mainstem Colorado River and the Little Colorado River (Task A-2.3) that are necessary for all life stages of humpback chub to support a recovered Grand Canyon population, 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.

3. Temperature control device for Glen Canyon Dam implemented, if determined feasible and necessary for recovery of humpback chub (Task A-3.2).

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

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

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

5. Identified levels of Asian tapeworm control to minimize the negative effects of parasitism on the humpback chub population attained in the Little Colorado River (Task C-1.2).

6. Procedures finalized and implemented for stocking and to minimize escapement of nonnative fish species into the Colorado River and its tributaries through Grand Canyon to minimize negative interactions between nonnative fishes and humpback chub (Task C-2.2).

7. Identified levels of rainbow trout, channel catfish, black bullhead, and common carp control to minimize predation on humpback chub attained in the Little Colorado River (Task C-3.2).

8. Identified levels of brown trout and rainbow trout control to minimize predation on humpback chub attained in the Colorado River through Grand Canyon (Task C-3.4).

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

9. Habitat necessary to provide adequate habitat and sufficient range for all life stages of humpback chub to support a recovered Grand Canyon population is legally protected in perpetuity (Task D-1.2).

10. 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 the recovered Grand Canyon humpback chub population will be maintained (Task D-2.2).

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

11. State and Federal emergency-response plans implemented that contain the necessary preventive measures for hazardous-materials spills (Task E-1.2).

12. Measures finalized and implemented to minimize the risk of hazardous-materials spills from transport of materials along U.S. Highway 89 at and near the two Cameron bridges spanning the Little Colorado River (Task E-1.4).

## 5.4 Estimated Time to Achieve Recovery of the Humpback Chub

Estimated time to achieve recovery of the humpback chub is 5 years for downlisting and an additional 3 years for delisting. First reliable point estimates are expected for all populations by 2002. If those estimates are acceptable to the Service and all recovery criteria are met, downlisting could be proposed in 2007 and delisting could be proposed in 2010 (Figure 2). This estimated time frame is based on current understanding of the status and trends of populations and on the monitoring time required to meet the downlisting and delisting criteria.

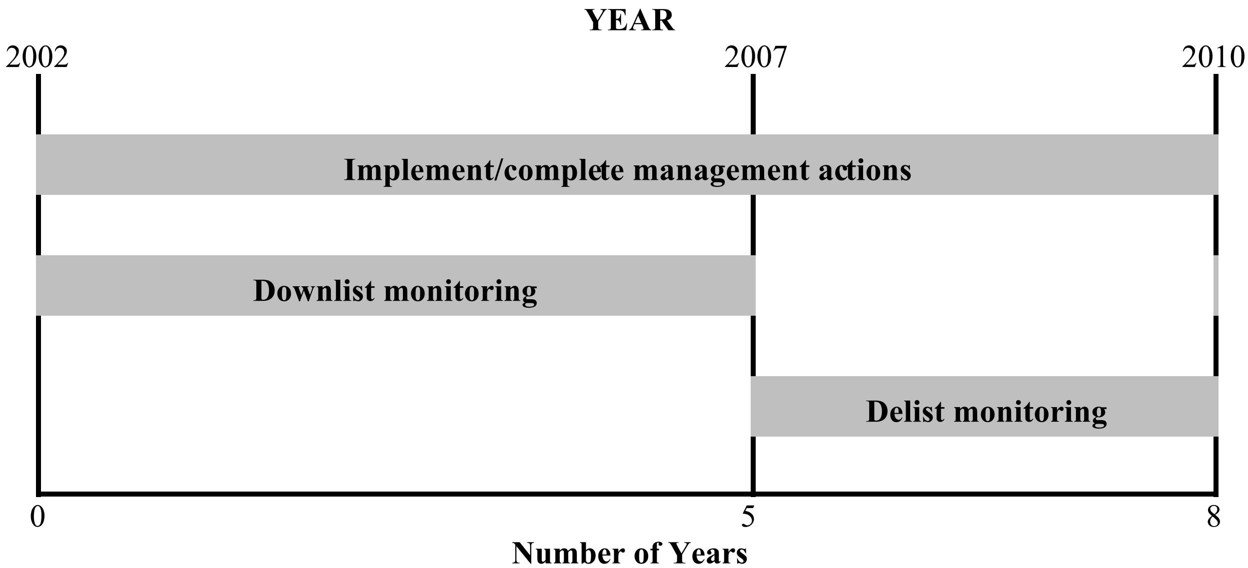


Figure 2. Estimated time to achieve recovery of the humpback chub.

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# APPENDIX A.

## LIFE HISTORY OF THE HUMPBACK CHUB

Following is a synopsis of humpback chub life history. This assimilation of information represents an overview of the best scientific information available for the species at this time. 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 humpback chub is a big-river cyprinid with maximum size of about 480 mm total length (TL) and 1,165 g (Valdez and Ryel 1997). The body is laterally compressed and fusiform, tapering abruptly to a narrow caudal peduncle (tail trunk) with a deeply forked tail fin and large fan-like falcate fins. A fleshy dorsal hump develops behind the head as the fish matures. Subadults have an olivaceous back and silvery sides fading to a creamy white belly; adults are light olivaceous and slate-gray dorsally and laterally, with a white belly tinged with light orange and yellow. Spawning adults in March–June are tinged with rosy-red gill coverings, paired fins, and belly; they develop pimple-like tubercles on the head and paired fins. The head is narrow and flattened and may be dorsally concave, with small eyes and a protruding fleshy snout and inferior, subterminal mouth. Dorsal and anal fins typically have 9 and 10 principal rays, respectively. Scales are deeply embedded, isolated dorsally and imbricated laterally and ventrally, with the head and nuchal hump devoid of scales. The pharyngeal arch is small with a short lower ramus and deciduous teeth in a typical pattern of 2,5-4,2 (Miller 1946).

### A.2 Distribution and Abundance

Historic abundance of the humpback chub is unknown, and historic distribution is surmised from various reports and collections that indicate the species presently occupies about 68% of its historic habitat of about 756 km of river. The species exists primarily in relatively inaccessible canyons of the Colorado River Basin and was rare in early collections (Tyus 1998). Common use of the name "bonytail" for all six Colorado River species or subspecies of the genus *Gila* confounded an accurate early assessment of distribution and abundance (Holden and Stalnaker 1975a, 1975b; Valdez and Clemmer 1982; Minckley 1996). Of three closely related and sympatric *Gila* species, the roundtail chub (*G. robusta*) and bonytail (*G. elegans*) were described in 1853 by Baird and Girard (Sitgreaves 1853; Girard 1856), but the humpback chub was the last big-river fish species to be described from the Colorado River Basin in 1946 (Miller 1946). Also, extensive human alterations throughout the basin prior to faunal surveys may have depleted or eliminated the species from some river reaches before its occurrence was documented.

It is surmised that the humpback chub speciated from a *G. robusta*-like form in canyons of northern Arizona (i.e., Grand Canyon) about 3–5 million years ago (Miller 1946; Uyeno and Miller 1965; Holden 1968; Minckley et al. 1986) during the mid-Pliocene and early Pleistocene epochs. Earliest evidence of the species are skeletal remains from 4,000-year old flood deposits in Stanton's Cave in Grand Canyon (Miller 1955; Euler 1978; Miller and Smith 1984), from a 750–1,100-year old archeological site in Catclaw Cave near present-day Hoover Dam (Miller 1955; Jones 1985), and from 1,000-year old archeological sites in Dinosaur National Monument, Colorado (Tyus 1998).

Earliest collections of humpback chub are anecdotal and related to early explorations of the Colorado River Basin that pre-date the species description in 1946. In 1911, Elsworth and Emory Kolb (Kolb and Kolb 1914) reported a large aggregation of *"bony tail"* in the lower Little Colorado River (LCR) in Grand Canyon; photographs show that the fish were humpback chub. A specimen in the fish collection at Grand Canyon National Park, caught in 1932 by angler N.N. Dodge at Bright Angel Creek, was examined in fall 1942 and used as the holotype for the species description (Miller 1946), along with a second specimen of unknown origin. In the 1940's, five specimens of humpback chub were collected from the Grand Canyon region along with 16 specimens of *G. elegans* and six *G. robusta* (Miller 1944; Bookstein et al. 1985). In 1950, juvenile humpback chub were reported from Spencer Creek in lower Grand Canyon (Wallis 1951; Kubly 1990), but icthyofaunal surveys in 1958–1959 (McDonald and Dotson 1960) failed to find humpback chub immediately upstream in the gentle meandering reaches of Glen Canyon.

Following completion of Glen Canyon Dam in 1963, humpback chub were consistently reported by Arizona Game and Fish Department creel surveys from Lee Ferry during 1963–1968 (Stone 1964, 1966; Stone and Queenan 1967; Stone and Rathbun 1968). However, Stone and Rathbun (1968) failed to find humpback chub in seven tributaries sampled between Lee Ferry and Lake Mead in 1968, excluding the LCR. Humpback chub were captured in July 1967 and August 1970 (Holden and Stalnaker 1975b), all within *"...a few hundred meters downstream of Glen Canyon Dam"* (personal communication, P. Holden, Bio/West, Inc.). Humpback chub have not been captured in this reach since the dam began releasing cold hypolimnetic waters in about 1970. Humpback chub have consistently been reported in the LCR and Colorado River in Grand Canyon since 1967 as a result of better sampling gear and a better understanding of the life history of the species (Stone and Rathbun 1968; Miller and Smith 1972; Holden and Stalnaker 1975b; Suttkus et al. 1976; Minckley and Blinn 1976; Suttkus and Clemmer 1977; Carothers et al. 1981; Kaeding and Zimmerman 1983; Maddux et al. 1987; Valdez and Ryel 1995; Arizona Game and Fish Department 1996a; Douglas and Marsh 1996).

Humpback chub were first reported in the Upper Colorado River Basin in the 1940's from Castle Park, Yampa River, Colorado, in June and July 1948 (Tyus 1998). Pre-impoundment surveys of Flaming Gorge Dam on the Green River in 1958–1959 (Bosley 1960; Gaufin et al. 1960; McDonald and Dotson 1960) treated all *Gila* as *"bonytail"*, which were common downstream of Green River, Wyoming. Humpback chub were reported from Hideout Canyon in the upper Green River (Smith 1960), although a checklist of fish killed by a massive rotenone operation from Hideout Canyon to Brown's Park in September 1962 stated that *"...no humpback chub were collected..."* (Binns 1967). Post-impoundment investigations (Vanicek et al. 1970) reported three humpback chub from the Green River downstream of Flaming Gorge Dam; one each from Echo Park, Island Park, and Swallow Canyon. Specimens were collected in Desolation Canyon on the Green River in 1967 (Holden and Stalnaker 1970), in Yampa Canyon in 1969 (Holden and Stalnaker 1975b), in Cross Mountain Canyon of the Yampa River in the 1970's (personal communication, C. Haynes), and an individual specimen was reported from the White River in Utah in the 1950's (Sigler and Miller 1963). Seven suspected humpback chub were captured in the Little Snake River, a tributary of the Yampa River, in 1988 (Wick et al. 1991). Surveys downstream of Flaming Gorge Dam, including Lodore Canyon, have not yielded humpback chub in that region of the Green River, despite warmer dam releases (Holden and Crist 1981; Bestgen and Crist 2000).

Five specimens were reported from Lake Powell in the late 1960's (Holden and Stalnaker 1970) following completion of Glen Canyon Dam in 1963 and impoundment of the upper Colorado River through Glen, Narrow, and Cataract canyons. Reproducing populations of humpback chub were first reported from Black Rocks, Colorado in 1977 (Kidd 1977), and from Westwater and Cataract canyons, Utah, in 1979 (Valdez et al. 1982; Valdez and Clemmer 1982).

Six humpback chub populations are currently identified: (1) Black Rocks, Colorado; (2) Westwater Canyon, Utah; (3) LCR and Colorado rivers in Grand Canyon, Arizona; (4) Yampa Canyon, Colorado; (5) Desolation/Gray Canyons, Utah; and (6) Cataract Canyon, Utah (see Figure 1 in section 3.1.2; Valdez and Clemmer 1982; U.S. Fish and Wildlife Service 1990a). Each population consists of a discrete group of fish, geographically separated from the other populations, but with some exchange of individuals. River length occupied by each population varies from 3.7 km in Black Rocks to 73.6 km in Yampa Canyon.

## A.3 Hybridization

The humpback chub is part of a morphologically diverse group of western cyprinids that includes several congeneric species. This *Gila* complex consists of six forms that inhabit the Colorado River Basin, including the humpback chub, roundtail chub, bonytail, Virgin River chub *(G. robusta seminuda)*, Pahranagat roundtail chub *(G. r. jordani),* and Gila chub *(G. intermedia)*. The humpback chub, bonytail, and roundtail chub are mainstem sympatric species with substantial evidence of introgressive hybridization (Dowling and DeMarais 1993). The Virgin River chub, Pahranagat roundtail chub, and Gila chub are isolates and primarily tributary inhabitants, although historic hybridization with other forms of *Gila* is evident. Humpback chub and bonytail appear to be specialized derivatives of the roundtail chub complex, and may have arisen in response to special conditions in large erosive habitats (Smith et al. 1979; Minckley et al. 1989); a hypothesis that is supported by recent allozyme and mitochondrial DNA analysis (Dowling and DeMarais 1993).

Intraspecific and interspecific morphological variation can be extensive where humpback chub, roundtail chub, and bonytail occur sympatrically. This apparent introgressive hybridization has resulted in high phenotypic plasticity with morphologic intergrades present in all sympatric populations of Colorado River *Gila* (Holden and Stalnaker 1970; Smith et al. 1979; Valdez and Clemmer 1982; Kaeding et al. 1990; Wick et al. 1991; McElroy and Douglas 1995; Douglas et al. 1998). These intergrades suggest, to some, extensive hybridization with possible concomitant loss of genetic diversity and evolutionary adaptive traits (Valdez and Clemmer 1982; Rosenfeld and Wilkinson 1989). Others suggest that introgressive hybridization is part of the common evolutionary history of the Colorado River *Gila*, resulting in high phenotypic plasticity and adaptability to the rigorous physical habitats present in the Colorado River Basin (Dowling and DeMarais 1993). Evidence of intergrades was reported prior to extensive human alterations to the basin (Miller 1946).

Because only two of the three congeneric and sympatric species of the *Gila* complex are Federally listed as endangered (i.e., humpback chub and bonytail), fish managers are compelled to distinguish these from the nonlisted roundtail chub. Morphologic variation in these species has led to confusion in field identification, especially for young fish (Douglas et al. 1998). This confusion has precluded accurate assessment of life history characteristics attributable to one species and definitive estimates of abundance; e.g., the inability to distinguish sympatric young humpback chub from roundtail chub afield has precluded species separation for the purpose of estimating densities and survival (Chart and Lentsch 1999, 2000).

Proportions of humpback chub, roundtail chub, bonytail, and intergrades from each of the six populations of humpback chub are shown in Table A-1. Proportions of these phenotypes in Black Rocks and Westwater Canyon vary primarily because of increased invasion of these canyon areas by roundtail chub during low water years (Chart and Lentsch 1999). Despite this variation, overall average proportions of humpback chub:roundtail chub:intergrades for Black Rocks and Westwater Canyon are similar as 48:45:8 and 44:45:12, respectively. Average proportions in Desolation/Gray Canyons of 19:7:74 show the highest proportions of intergrades of any population of humpback chub. Proportions in the LCR and Colorado River in Grand Canyon are 100% humpback chub because the known genotype is primarily of this form (Dowling and DeMarais 1993), and recent samples show little evidence of other phenotypes in this population (McElroy and Douglas 1995). Proportions of 46:23:13:18 in Cataract Canyon include bonytail and indicate a large diverse complex of *Gila* associated with this population (McElroy and Douglas 1995). The proportion of 14:86:0 in Yampa Canyon shows a large percentage of roundtail chub relative to humpback chub and little or no intergradation between these forms.

Proportions of humpback chub to roundtail chub and catch rates recorded by investigators in Black Rocks (Kaeding et al. 1990) and Westwater Canyon (Chart and Lentsch 2000) reveal a greater proportion of roundtail chub in these areas in years of low flow; it is hypothesized that lower velocities and less turbulence in low water years allow roundtail chub to invade canyon regions not normally inhabited by this species. Increased sympatry of these species potentially increases the chances for hybridization; hybridization has been demonstrated in a hatchery among all three *Gila* species. Hence, it is necessary to provide flow regimes that reflect inter-annual variability in hydrologic conditions (e.g., wet, average, and dry water years) in order to maintain natural proportions of *Gila* species and intergrades.

## A.4 Habitat

The humpback chub evolved in seasonally warm and turbid water and is highly adapted to the unpredictable hydrologic conditions that occurred in the pristine Colorado River system. Adults require eddies and sheltered shoreline habitats maintained by high spring flows. These high spring flows maintain channel and habitat diversity, flush sediments from spawning areas,

Table A-1. Proportion of *Gila cypha*, *G. robusta*, *G. elegans*, and intergrades in six populations of humpback chub, based on morphology of adult specimens.

| Population or Habitat | Years Sampled | Total Number (N) | Percent of Total Number | | | | Source |
|---|---|---|---|---|---|---|---|
| | | | *G. cypha* | *G. robusta* | *G. elegans* | Intergrades | |
| Upper Basin | | | | | | | |
| Black Rocks | 1979–81 | 552 | 29 | 70 | 0 | 1 | Valdez et al. (1982) |
| | 1983–85 | 569 | 47 | 44 | <1 | 9 | Kaeding et al. (1990) |
| | 1988 | 91 | 58 | 39 | 0 | 3 | McAda et al. (1994) |
| | 1991 | 127 | 58 | 25 | 0 | 17 | McAda et al. (1994) |
| Westwater Canyon | 1979–81 | 226 | 19 | 77 | 0 | 4 | Valdez et al. (1982) |
| | 1986 | 126 | 36 | 31 | 0 | 33 | McAda et al. (1994) |
| | 1988 | 143 | 72 | 27 | 0 | 1 | McAda et al. (1994) |
| | 1991 | 247 | 47 | 45 | 0 | 8 | McAda et al. (1994) |
| Yampa Canyon | 1986–89 | 922 | 14 | 86 | 0 | 0 | Karp and Tyus (1990) |
| Desolation/Gray Canyons | 1992 | 24 | 46 | 29 | 0 | 25 | Chart and Lentsch (2000) |
| | 1993 | 43 | 5 | 0 | 0 | 95 | Chart and Lentsch (2000) |
| | 1994 | 41 | 10 | 5 | 0 | 85 | Chart and Lentsch (2000) |
| | 1995 | 48 | 25 | 4 | 0 | 71 | Chart and Lentsch (2000) |
| | 1996 | 26 | 23 | 8 | 0 | 69 | Chart and Lentsch (2000) |
| Cataract Canyon | 1979–81 | 48 | 46 | 23 | 13 | 18 | Valdez (1990) |
| Lower Basin–Grand Canyon | | | | | | | |
| Little Colorado River | 1980–81 | 433 | 100 | 0 | 0 | 0 | Kaeding and Zimmerman (1983) |
| Colorado River | 1990–93 | 1791 | 100 | 0 | 0 | 0 | Valdez and Ryel (1995) |

rejuvenate food production, and form gravel and cobble deposits used for spawning. Spawning occurs on the descending limb of the spring hydrograph at water temperatures typically between 16 and 22°C. Young require low-velocity shoreline habitats, including eddies and backwaters, that are more prevalent under base-flow conditions. Flow recommendations have been developed that specifically consider flow-habitat relationships in habitats occupied by humpback chub 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 habitat uses in various parts of the Colorado River Basin.

Humpback chub live and complete their entire life cycle in canyon-bound reaches of the Colorado River mainstem and larger tributaries. These reaches are characterized by deep water, swift currents, and rocky substrates (Valdez et al. 1990). Subadults use shallow, sheltered shoreline habitats, whereas adults use primarily offshore habitats of greater depths (Valdez and Ryel 1995; Karp and Tyus 1990; Childs et al. 1998; Chart and Lentsch 1999). In Grand Canyon, nearly all fish smaller than 100 mm TL were captured near shore, whereas most fish larger than 100 mm TL were captured in offshore habitats (Valdez and Ryel 1995). Highest densities of subadults in the Colorado River in Grand Canyon were from shorelines with vegetation, talus, and debris fans (Converse et al. 1998). Adults were captured (88%) and radio-contacted (74%) primarily in large recirculating eddies disproportionate to their availability (21%; Valdez and Ryel 1997). Smaller percentages of adults were captured or radio contacted in runs (7% and 16%, respectively) that comprised 56% of surface area, pools (1% and 3%, respectively) that comprised 16% of surface area, and backwaters (4% and 7%, respectively) that comprised 0.1% of surface area (Table A-2). Adults remained in similar habitats during an experimental flood through Grand Canyon (Arizona Game and Fish Department 1996b; Valdez and Hoffnagle 1999).

Table A-2. Habitat of adult humpback chub in the Colorado River in Grand Canyon (Valdez and Ryel 1997).

| Capture or Radio-contact | Habitats (Percent of Surface Area) | | | | |
|---|---|---|---|---|---|
| | Eddies | Runs | Pools | Backwaters | Other |
| Captures (1,579 fish) | 88 | 7 | 1 | 4 | 0 |
| Radio-contacts (835 from 75 fish) | 74 | 16 | 3 | 7 | <0.1 |
| Surface Riverine Area | 21 | 56 | 16 | <0.1 | 7 |

As young humpback chub grow, they exhibit an ontogenic shift toward deeper and swifter offshore habitats. In Westwater Canyon during summer, fish smaller than 40 mm TL used low-velocity areas, including backwaters and shorelines. Later in summer and fall, as fish attained sizes of 40–50 mm TL, their habitat use shifted toward higher-velocity, flowing-water habitats (Chart and Lentsch 1999). Karp and Tyus (1990) reported similar habitat use by larger humpback chub, noting that fish 88–228 mm TL in the Yampa and Green rivers used habitats consisting of rocky shoreline runs and small shoreline eddies. Average depths selected by larvae, young-of-year, juveniles, and adults in the upper basin were 0.4, 0.6, 0.7, and 3.1 m, respectively (Valdez et al. 1990), and average velocities were 0.03, 0.06, 0.18, and 0.18 m/s, respectively. Dominant substrates were silt and sand for Young-of-year, and boulders, sand, and bedrock for juveniles and adults.

Valdez and Ryel (1995, 1997) also reported ontogenic shifts in habitat use by humpback chub in Grand Canyon. In the mainstem Colorado River, juveniles (50–200 mm TL) used primarily shallow shoreline habitats; adults primarily used offshore habitats at greater depths. Minimum, average, and maximum velocities selected by young-of-year (21–74 mm TL) were 0.0, 0.06, and 0.30 m/s, respectively, all at depths less than 1 m. Minimum, average, and maximum velocities selected by humpback chub (75–259 mm TL) were 0.0, 0.18, and 0.79 m/s, respectively, all at depths less than 1.5 m. In the LCR, larval and early juvenile humpback chub used shallow, low-velocity habitats, different than those used by young of other native species, indicating resource partitioning (Childs et al. 1998). Gorman (1994) found that juveniles or early stages less than

50 mm TL occupied near-benthic to mid-pelagic positions in shallow, nearshore areas that were less than 10 cm deep and had low-velocity flow, small substrate particle sizes, moderate cover, and vertical structure. Larger juveniles or fish 50–100 mm TL used similar habitats of moderate depth (less than 20 cm) that had small to large substrate particle size, moderate to high cover, and vertical structure. Juveniles (100–150 mm TL) used shoreline and offshore areas of moderate to deep water (less than 30 cm during the day; less than 20 cm at night) that had slow currents, small and large substrate particle size, moderate to high levels of cover, and vertical structure.

Little is known about spawning habitats of adult humpback chub during high spring-runoff flows. Habitats where ripe humpback chub have been collected are typically deep, swift, and turbid. As a result, spawning in the wild has not been directly observed. Gorman and Stone (1999) reported that ripe male humpback chub in the LCR aggregated in areas of complex habitat structure (i.e., matrix of large boulders and travertine masses combined with chutes, runs, and eddies, 0.5–2.0 m deep) and were associated with deposits of clean gravel. Valdez and Ryel (1995, 1997) reported that during spring, adult humpback chub in the Colorado River in Grand Canyon primarily used large recirculating eddies, occupying areas of low velocity adjacent to high-velocity currents that deliver food items. They also reported that adults congregated at tributary mouths and flooded side canyons during high flows.

In the Upper Colorado River Basin during spring runoff, spawning adult humpback chub appear to utilize cobble bars and shoals adjacent to relatively low-velocity shoreline habitats that are typically described as shoreline eddies (Valdez et al. 1982; Karp and Tyus 1990; Valdez et al. 1990; Valdez and Ryel 1995, 1997). Tyus and Karp (1989) reported that humpback chub in the Yampa River occupy and spawn in or near shoreline eddy habitats. They also hypothesized that spring peak flows were important for reproductive success because availability of these habitats is greatest during spring runoff; loss or reduction of spring peak flows could potentially reduce availability of spawning habitat.

## A.5 Movement

Humpback chub move substantially less than other native Colorado River fishes (Valdez and Carothers 1998). Radiotelemetry and tagging studies consistently show high fidelity by humpback chub for specific riverine locales occupied by respective populations. Mean net movement of eight radio-tagged adults in Black Rocks was 0.8 km over a maximum of 93 days (range, 30–170 days), and average distance between captures for 218 Carlin-tagged fish in Black Rocks and Westwater Canyon over a maximum of 434 days was 1.6 km for 1980–1981 (Valdez and Clemmer 1982). A second study in Black Rocks found similar results with mean maximum displacement of 33 radio-tagged adults of 1.4 km, and 63 Carlin-tagged fish at large up to 56 months were recovered 1.1 km from release sites during 1988–1989 (Kaeding et al. 1990). In the Colorado River in Grand Canyon, mean net movement of 69 radio-tagged adults monitored year-around for an average of 93 days (range, 30–170 days) was 1.49 km (range, 0–6.11 km); 51% moved less than 1 km and 84% moved less than 3 km. This was comparable to net movement of 1.94 km (range, 0–99.8 km) for 188 PIT-tagged fish at large 20–1,065 days (i.e., up to 2.9 years) for the same study and area. Mark-recapture data from 92 humpback chub with Carlin and Floy tags and at large for an average of 2,990 days (range, 304–4,496 days; up to 12.3 years) showed average distance from original capture to recapture of 4.29 km (range, 0.1–14.4 km), revealing remarkable fidelity for specific river locales (Valdez and Ryel 1995, 1997). In contrast, net movement of 43 radio-tagged Colorado pikeminnow (*Ptychocheilus lucius*) in fall and spring in the upper basin was 31.8 km (Archer et al. 1985), and 33.9 km for radio-tagged adult roundtail chub in spring and summer (Kaeding et al. 1990). Although Colorado pikeminnow have considerable fidelity to winter home ranges, round trip movements during spawning migrations may be up to 950 km.

Despite remarkable fidelity for given river regions, individual humpback chub adults have been known to move between populations. Of 218 fish tagged in Black Rocks and Westwater Canyon in 1980, 16 were recaptured, with one (6%) having moved 23 km from Westwater Canyon upstream to Black Rocks (Valdez and Clemmer 1982). Kaeding et al. (1990) recaptured 63 tagged fish, with two (3%) having moved from Westwater Canyon upstream to Black Rocks. These studies indicate an exchange of 3–6% of these populations over the periods of study (i.e., 2–3 years). Two additional exchanges between these populations (Black Rocks downstream to Westwater Canyon) have been documented more recently (Chart and Lentsch 1999), showing that movement occurs to and from each population. Considering that the generation time of humpback chub is approximately 8 years (= mean adult age of 4 plus [1/d], where d is the death rate; = 4 + [1/1-0.76] = 4+4 = 8; Seber 1982), the indicated level of exchange suggests far more than a minimum of one migrant per generation, which is considered the necessary level of connectivity to minimize the loss of polymorphism and heterozygosity in wild animal populations (Mills and Allendorf 1996).

Greatest movement of humpback chub has been reported from Grand Canyon, primarily because adults from the mainstem annually ascend the LCR to spawn (Valdez and Ryel 1995). Average movement of 401 PIT-tagged fish marked in the mainstem and recaptured in the LCR was 7.2 km (range, 0.08–34.1 km). However, most of these fish returned to the mainstem with remarkable fidelity to mainstem locales. Of 60 PIT-tagged fish consecutively captured in the mainstem, then the LCR, and again in the mainstem, 54 (90%) returned to within 2 km of their original mainstem locale; 31 (52%) were recaptured within 0.5 km; and 10 (17%) were recaptured within 0.1 km. No significant difference in movements was noted between male and female humpback chub. Fish moving from the mainstem to the LCR and back to the mainstem tended to be larger fish than those remaining in the LCR (81% were > 300 mm TL).

Movement by juveniles is not as well documented as for adults, but is also believed to be limited in distance. No out-migration by young fish is seen from population centers such as Black Rocks and Westwater Canyon (Valdez et al. 1982; Chart and Lentsch 1999). However, Valdez and Ryel (1995, 1997) reported large numbers of juveniles moving downstream from the LCR into the Colorado River in Grand Canyon during monsoonal freshets; it is not clear if this movement is active or passive. Hoffnagle (1995) reported greater nighttime use of backwaters in Grand Canyon by juvenile humpback chub and flannelmouth sucker (*Catostomus latipinnis*). Juveniles and subadults were nocturnally active, and post-larvae and young-of-year were diurnally active, primarily in the morning and at night.

## A.6 Reproduction

The humpback chub is an obligate warm-water species that requires relatively warm temperatures for spawning, egg incubation, and survival of larvae. Highest hatching success is at 19–20°C with incubation time of 3 days, and highest larval survival is slightly warmer at 21–22°C. Hatching success under laboratory conditions was 12%, 62%, 84%, and 79% in 12–13°C, 16–17°C, 19–20°C, and 21–22°C, respectively, whereas survival of larvae was 15%, 91%, 95%, and 99%, at the same respective temperatures (Table A-3; Hamman 1982). Time from fertilization to hatching ranged from 465 hours at 10.0°C to 72 hours at 26.0°C, and time from hatching to swim-up varied from 372 hours at 15.0°C to 72 hours at 21.0–22.0°C. Marsh (1985) found similar results. Proportion of abnormal fry varied with temperature and was highest at 15.0°C (33%) and 25.0°C (17%). Marsh and Pisano (1985) also found optimum spawning temperature of 19–20°C, and total mortality of embryos at 5, 10, and 30°C.

Table A-3. Hatching success and larval survival for humpback chub at various temperatures in laboratory conditions (Hamman 1982).

| Parameter | Temperature | | | |
|---|---|---|---|---|
| | 12–13°C | 16–17°C | 19–20°C | 21–22°C |
| Hatching Success (%) | 12 | 62 | 84 | 79 |
| Larval Survival (%) | 15 | 91 | 95 | 99 |

Humpback chub are broadcast spawners with a relatively low fecundity rate, compared to cyprinids of similar size (Carlander 1969). Eight humpback chub (355–406 mm TL), injected with carp pituitary and stripped in a hatchery, produced an average of 2,523 eggs/female, or about 5,262 eggs/kg of body weight (Hamman 1982). Egg diameter ranged from 2.6 to 2.8 mm (mean, 2.7 mm). Eleven humpback chub from the LCR yielded 4,831 eggs/female following variable injections of carp pituitary and field stripping (Clarkson 1993). Male to female ratios for mainstem adults captured near the LCR, based on external morphological examination of papillae and expression of gametes, ranged by sample from 41:59 to 53:47, for an overall average of 49:51 (Valdez and Ryel 1995). Observed male to female ratio of humpback chub in Westwater Canyon was 58:42 (Chart and Lentsch 1999).

Humpback chub spawn primarily during March–May in the LCR (Kaeding and Zimmerman 1983; Minckley 1996; Gorman and Stone 1999; Stone 1999) and during April–June in the upper basin (Kaeding et al. 1990; Valdez 1990; Karp and Tyus 1990). In the LCR, ripe males aggregated in areas of complex habitat structure (Gorman and Stone 1999), and gravid females appeared to move to these male aggregations to spawn. Abrasions on anal and lower caudal fins of males and females in the LCR and in Cataract Canyon (Valdez 1990) suggest that spawning involves rigorous contact with gravel substrates, although actual spawning events have not been observed.

Unlike larvae of other Colorado River fishes (e.g., Colorado pikeminnow and razorback sucker), larval humpback chub show no evidence of long-distance drift (Robinson et al. 1998). At hatching, larvae have nonfunctional mouths and small yolk sacs (Muth 1990). The larvae swim up about 3 days after hatching but tend to remain close to spawning sites. Robinson et al. (1998) found small numbers of larvae drifting in the LCR from May through July, primarily at night.

The presence of juveniles in populations with complete size structure suggests successful reproduction in all or portions of the six populations; i.e., Black Rocks (Kaeding et al. 1990), Westwater Canyon (Chart and Lentsch 1999), the LCR in Grand Canyon (Douglas and Marsh 1996, Gorman and Stone 1999), Cataract Canyon (Valdez 1990), Desolation/Gray Canyons (Chart and Lentsch 2000), and Yampa Canyon (Karp and Tyus 1990). Reproduction in the mainstem Colorado River in Grand Canyon is precluded by cold-water temperatures, and the only documented evidence of reproduction (i.e., post-larvae) is in a thermal riverside spring located 72 km downstream of Glen Canyon Dam (Valdez and Masslich 1999). The large size structure of the humpback chub aggregation associated with this spring indicates little or no recruitment (Valdez and Ryel 1995).

## A.7 Survival

Survival of humpback chub during the first year of life is low, but increases through the first 2–3 years of life with decreased susceptibility to predation, starvation, and environmental changes. Survival of adults is markedly higher than that of subadults. Annual survival rate of subadult humpback chub in the mainstem Colorado River in Grand Canyon through the first 3 years of life was estimated at 0.10, based on monthly electrofishing and minnow trap catches along shorelines near the LCR (Valdez and Ryel 1995, 1997). Survival from larval to adult life stages was estimated at 0.001 ($0.10^3$). Survival rate of young fish apparently varies with presently unknown environmental factors. Survival rates of young-of-year humpback chub of the 1991 year class, based on monthly electrofishing, were 0.824, 0.312, and 0.097 for 1, 6, and 12 months, respectively, and rates for 1992 were similar at 0.829, 0.326, and 0.106, respectively. However, survival rates for the 1993 year class, following high reproductive success, were much lower at 0.216, $1 \times 10^{-4}$, and $1 \times 10^{-8}$ for 1, 6, and 12 months, respectively. The decrease in density of subadults from September to November 1993 was 95% (521 to 24 fish/10 hours; Valdez and Ryel 1995), and was comparable to a 98% decrease (2,082 to 58) in total catch of subadults in backwaters (i.e., eddy return-current channels; Arizona Game and Fish Department 1994). Fall density of the 1993 year class was comparable to that of the 1991 and 1992 year classes, suggesting density-dependent mortality of first-year humpback chub in the mainstem.

Annual survival rate of mainstem Grand Canyon adults, based on mark-recapture data and open population model estimates, was 0.755 (95% C.I. = 0.627–0.896; Valdez and Ryel 1995). Survival rate between seasons was estimated at 0.932 (95% C.I. = 0.890–0.973). According to these estimates, 204–238 adults are lost seasonally out of a population of 3,000–3,500, and 735–857 are lost annually. Survival rates were not available for humpback chub from the LCR or from other populations in the basin.

## 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 1998). 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 species were intentionally introduced as game or forage fishes, 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 (e.g., Tyus and Beard 1990; Minckley 1991; Hawkins and Nesler 1991; Ruppert et al. 1993; Lentsch et al. 1996; Tyus and Saunders 1996; Pacey and Marsh 1998).

The threat of predation by nonnative fishes on humpback chub has been recognized in three populations. In Grand Canyon, brown trout (*Salmo trutta*), channel catfish (*Ictalurus punctatus*), black bullhead (*Ameiurus melas*), and rainbow trout (*Oncorhynchus mykiss*) have been identified as principal predators of juvenile humpback chub, with consumption estimates that suggest loss of complete year classes to predation (Marsh and Douglas 1997; Valdez and Ryel 1997). Marsh and Douglas (1997) documented predation on humpback chub in the LCR by rainbow trout, channel catfish, and black bullhead. Valdez and Ryel (1997) identified brown trout, rainbow trout, and channel catfish as known predators of humpback chub in Grand Canyon, and suggested that common carp (*Cyprinus carpio*) could be a significant predator of incubating humpback chub eggs in the LCR. In the upper basin, Chart and Lentsch (2000) identified channel catfish as the principal predator of humpback chub in Desolation/Gray Canyons. The UCRRP identified channel catfish as the principal predator of humpback chub in Yampa Canyon and is pursuing development and implementation of a control program.

## A.9 Age and Growth

Use of scales for aging humpback chub has limited use because of crowding, extensive cross-overs, and loss of growth rings because of resorption (Valdez and Ryel 1995). The humpback chub is endangered, therefore sacrificing individuals for extracting otoliths (i.e., inner ear bones) or other bony structures for traditional age-growth studies is not practical. Length-frequency analyses distinguish only the first three or four cohorts and slowed growth distorts cohort separation after the fish reach maturity at about 175–200 mm TL. The only information available on growth of humpback chub is from laboratory studies with young fish, mark-recapture data, and a limited amount of scale aging of young individuals. A limited number of otoliths (lapilli) from LCR fish was examined for total age and showed a maximum of 23 annular rings (Hendrickson 1993), indicating that the species is long-lived; measurements of individual annual rings were not taken for age-growth analysis by back-calculation, and incomplete analyses render these results preliminary and putative.

Humpback chub grow relatively quickly at warm temperatures until maturity, at which time growth slows dramatically. Humpback chub larvae are approximately 7 mm long at hatching (Muth 1990). In a laboratory, post-larvae grew at a rate of 10.63 mm/30 days at 20°C, but only 2.30 mm/30 days at 10°C (Lupher and Clarkson 1994). Similar growth rates were reported from back-calculations of scale growth rings in wild juveniles at similar water temperatures from the LCR (10.30 mm/30 days; temperature of 18–25°C) and the mainstem Colorado River in Grand Canyon (3.50–4.00 mm/30 days; temperature of 10–12°C; Valdez and Ryel 1995). Clarkson and Childs (2000) found that lengths, weights, and specific growth rates of humpback chub were significantly lower at 10°C and 14°C (similar to hypolimnetic dam releases) than at 20°C.

Growth rates of humpback chub vary by population. Based on scale back-calculations, humpback chub from the LCR were 100 mm TL at 1 year of age and 250–300 mm TL at 3–4 years of age (Kaeding and Zimmerman 1983); whereas, fish 1, 2, and 3 years old from the mainstem Colorado River in Grand Canyon were 95, 155, and 206 mm TL, respectively (Valdez and Ryel 1995). Fish 1–6 years old from Cataract Canyon were 50, 100, 144, 200, 251, and 355 mm TL, respectively (Valdez 1990).

Mark-recapture data from the LCR (Minckley 1992) and the Colorado River in Grand Canyon (Valdez and Ryel 1995) show that young humpback chub grow faster in the LCR (about 10 mm/30 days) than in the mainstem (2–4 mm/30 days), but fish older than about 3 years of age grow faster in the mainstem (0.79–2.79 mm/30 days) than in the LCR (<1–1.4 mm/30 days). Apparently food resources, habitat, and water temperatures are more suitable for young fish in the LCR, but habitat, food, and space may be limiting for adults. Abundant habitat, suitable food, and a relatively stable, regulated flow may favor adult growth in the mainstem, despite cold water temperatures. Mark-recapture data for humpback chub from Westwater Canyon, Utah (personal communication, T. Chart, U.S. Bureau of Reclamation) showed average monthly growth rates of 1.08 mm and 1.35 mm for fish 200–250 mm TL and 250–300 mm TL, respectively, which are similar to the growth rates of LCR fish, but well below growth rates of mainstem Grand Canyon fish.

Age to length relationships for humpback chub are available from several investigations (Vanicek and Kramer 1969; Kaeding and Zimmerman 1983; Valdez 1990; Minckley 1992; Hendrickson 1993; Valdez and Ryel 1995; personal communication, G. Haines, U.S. Fish and Wildlife Service). Vanicek and Kramer (1969) determined average length of age-4 roundtail chub from the Green River at 218 mm TL, and average length of age-3 *"Colorado chub"* (*Gila* sp.) at 156 mm TL (based on scale back-calculations); roundtail chub can be used as a surrogate for humpback chub because of similar growth rates and lengths. Valdez (1990) determined average length of age-4 humpback chub in Cataract Canyon at 200 mm TL, and length of age 3 at 144 mm TL. Using 30-day growth rates of humpback chub from the LCR (Minckley 1992), lengths at ages 3 and 4 were estimated at 170 and 200 mm TL, respectively. Hendrickson (1993) aged humpback chub from the LCR and the mainstem Colorado River in Grand Canyon; based on polynomial regression of average number of annuli from otoliths (lapillus and asteriscus) and opercles, age-3 fish were 157 mm TL and age-4 fish were 196 mm TL (Figure A-1). Valdez and Ryel (1995) recorded size at first observed maturity (based on expression of gametes, presence of spawning tubercles) of humpback chub in Grand Canyon at 202 mm TL for males and 200 mm

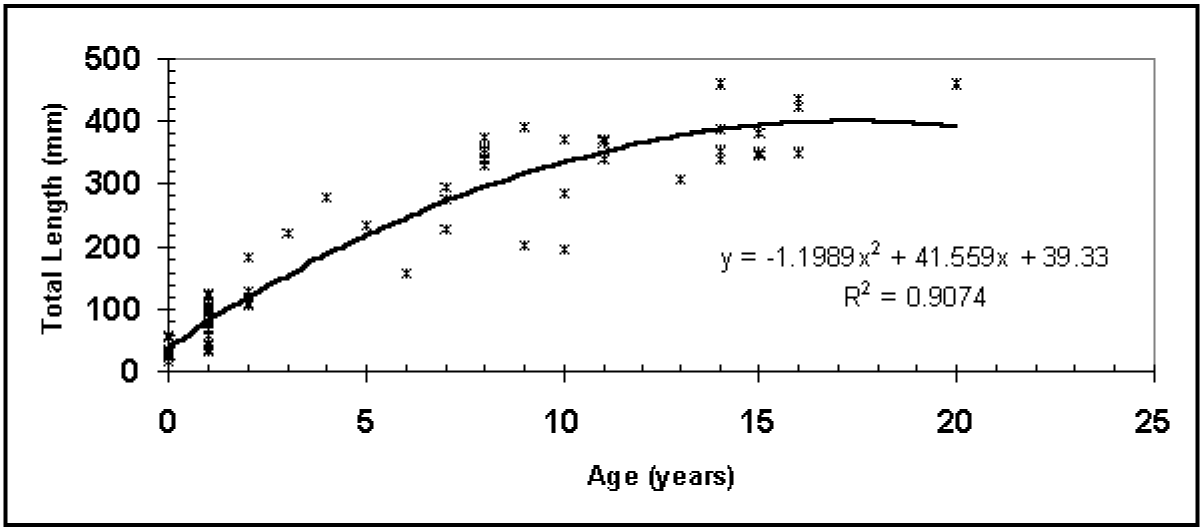


Figure A-1. Total length to age relationship for humpback chub from Grand Canyon, based on average number of annuli from otoliths (lapillus and asteriscus) and opercles (Hendrickson 1993).

TL for females; average length of age-3 fish, based on scale back-calculations, was 186 mm TL. In Yampa Canyon, approximate length of age-4 roundtail chub from otolith age (personal communication, G. Haines, U.S. Fish and Wildlife Service) was 200 mm TL, and approximate length at age 3 was 150 mm TL. These investigations show that average length of age-4 humpback chub ranged from 196 to 218 mm TL, and length of a tracked cohort was 140–210 mm TL (Table A-4). From this information on age at sexual maturity and age to length relationships, adult humpback chub are defined as fish that are 200 mm TL or larger. This is based on the conservative assumption that all age-4 fish are sexually mature, and the average length at age 4 is 200 mm TL. Based on an approximate length at age 3, subadults are defined as those fish that are 150–199 mm TL (Table A-4).

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

Length-weight relationships and condition factor provide valuable indices to the general health of a fish population. Length-weight relationships for mainstem Grand Canyon humpback chub for 1990–1991 (log W = -5.324 + 3.117 log TL, $R^2$ = 0.99), 1992 (log W = -5.176 + 3.056 log TL, $R^2$ = 0.99), and 1993 (log W = -5.034 + 2.986 log TL, $R^2$ = 0.98) reveal exponents of 3.117, 3.056, and 2.986, which indicate approximately isometric growth (Valdez and Ryel 1995); i.e., the relationship of weight as a cube of the length (exponent = 3.0) remains constant as the fish grows (LeCren 1951; Lagler 1956). However, Meretsky et al. (2000) provided length-weight relationships for eight groups of fish from all six populations of humpback chub; exponents ranged from 2.505 to 3.288, indicating different degrees of allometry among populations. Douglas (1993) reported from video image technology that changing body shape of humpback chub affects length to weight relationships, also suggesting allometric growth; no significant difference in morphology was found between males and females.

Table A-4. Lengths of adult and subadult humpback chub as determined from scale back-calculations, otolith and opercle ages, and field observations.

| Investigator | Area or Population | Adult | | Subadult | |
|---|---|---|---|---|---|
| | | Age | Total Length (mm) | Age | Total Length (mm) |
| Vanicek and Kramer (1969) | Dinosaur National Monument, Green River, Colorado and Utah | 4 | 218[a] | 3 | 156[b] |
| Valdez (1990) | Cataract Canyon, Colorado River, Utah | 4 | 200 | 3 | 144 |
| Minckley (1992) | Little Colorado River, Grand Canyon, Arizona | 4 | ~200[c] | 3 | ~170[c] |
| Hendrickson (1993) | Little Colorado River, Grand Canyon, Arizona | 4 | 196 | 3 | 157 |
| Valdez and Ryel (1995) | Colorado River, Grand Canyon, Arizona | | Males: 202<br>Females: 200[d] | 3 | 186 |
| Chart and Lentsch (1999) | Westwater Canyon, Utah | 4 | 140–210[e] | 3 | 120–170[e] |
| Haines (pers. comm.) | Yampa River, Colorado[f] | 4 | 200[a] | 3 | 150[a] |

[a]based on roundtail chub (*Gila robusta*).
[b]based on "Colorado chub" (*Gila* sp.).
[c]based on 30-day growth rates.
[d]based on size at first maturity from field observations.
[e]based on length ranges of cohorts tracked with length-frequency.
[f]based on otoliths.

Relative condition factor for adult humpback chub (>200 mm TL) from the mainstem Colorado River in Grand Canyon for 1990–1993 ranged from 0.783 to 1.023 for males and from 0.883 to 1.092 for females (Valdez and Ryel 1995). Highest condition was typically seen during February-April, just prior to spawning, and lowest condition was usually seen during June–September, after spawning. Meretsky et al. (2000) reported a decline in condition factor of adult humpback chub not in immediate spawning condition from the LCR confluence from 1978 to 1996, hypothesizing that the decline could be caused by one or more factors; e.g., a recent invasion of the Asian tapeworm (*Bothriocephalus acheilognathi*), researcher variation in weighing fish, or natural population variation.

Hoffnagle (2000) reported that condition and abdominal fat were greater in the mainstem Colorado River than in the LCR during 1996, 1998, and 1999. This may have been due to the increased prevalence and abundance of parasites (especially *Lernaea cyprinacea* and *Bothriocephalus acheilognathi*) in the LCR fish and/or greater food availability in the Colorado River.

## A.11 Diet

Humpback chub are typically omnivores with a diet consisting of insects, crustaceans, plants, seeds, and occasionally small fish and reptiles. They appear to be opportunistic feeders, capable of switching diet according to available food sources, and ingesting food items from the water's surface, mid-water, and river bottom. A number of investigators have reported large volumes of the green alga *Cladophora* mixed with a variety of invertebrates and detritus in diets of humpback chub from Grand Canyon (Minckley et al. 1980; Carothers and Minckley 1981; Kubly 1990; Valdez and Ryel 1995), suggesting that either incidentally consumed items are significant in the diet or nutritional value is gained from miscellaneous plant parts. Leibfried (1988) found that epiphytic diatoms on *Cladophora glomerata* consumed by rainbow trout provided an important source of lipids in the diet. This is unlikely for humpback chub because of a simple S-shaped gut with no defined stomach or lower intestine, and no pyloric caeca, all of which function in other fishes to help break down cellulose and absorb fats and nutrients.
The only detailed dietary studies of humpback chub are from Grand Canyon. Guts of 158 adults from the mainstem Colorado River, flushed with a nonlethal stomach pump, had 14 invertebrate taxa and nine terrestrial taxa (Valdez and Ryel 1995), including simuliids (blackflies, in 77.8% of fish), chironomids (midges, 57.6%), *Gammarus* (freshwater shrimp, 50.6%), *Cladophor*a (green alga, 23.4%), Hymenoptera (wasps, 20.9%), and cladocerans (water fleas, 19.6%). Seeds and human food remains were found in eight (5.1%) and seven (4.4%) fish respectively. Longitudinal differences in diet were evident reflecting relative abundance of available food sources; i.e., simuliids were available and consumed throughout the canyon, but terrestrial invertebrates replaced *Gammarus* in lower reaches where the latter were absent. Seasonal differences were also evident with *Gammarus* as the primary food item in spring (40.1% by volume), and simuliids in summer (46.4%) and fall (44.7%). Diets of adult humpback chub during an experimental high dam release in 1996 showed a preference for terrestrial insects and aquatic invertebrates dislodged by the flood and entrained in large recirculating eddies (Valdez and Hoffnagle 1999). Specimens caught below Glen Canyon Dam in the early 1970's had been feeding on zooplankton flushed from Lake Powell (Minckley 1973).

Diets of humpback chub from the LCR and mainstem differ markedly, reflecting available food sources. Although larvae of simuliids and chironomids were present in both groups, *Gammarus* comprised only 1% volume of the diet of LCR fish (Kaeding and Zimmerman 1983), but approximately 64% of the diet of mainstem fish (Valdez and Ryel 1995); *Gammarus* are abundant in the mainstem but rare in the LCR. Adult humpback chub from the LCR have also been reported to be cannibalistic on their young during periods of high reproductive success (Gorman 1994).

Arizona Game and Fish Department (1996a) reported that juvenile humpback chub in Grand Canyon consumed 19 different prey items, eight more than any other species examined. Chironomid larvae, terrestrial insects, simuliid larvae, and copepods were all found in at least 5% of the stomachs examined.

Diet studies for humpback chub from populations outside the Grand Canyon are limited. Analysis of 25 young-of-year and juvenile *Gila* spp. from the Green and upper Colorado Rivers showed that Ephemeroptera and Diptera were important food items (Jacobi and Jacobi 1982). The diet of "Colorado chub" (i.e., roundtail chub and bonytail) was chironomid larvae and ephemeroptera nymphs for small fish (< 200 mm TL), and aquatic and terrestrial insects (i.e., adult beetles, grasshoppers and ants) for larger fish (> 200 mm TL; Vanicek 1967). Tyus and Minckley (1988) reported that humpback chub utilized migrating Mormon crickets (*Anabrus simplex*), a large flightless locust, in the Green and Yampa rivers within Dinosaur National Monument. These studies also suggest that humpback chub are opportunistic in their feeding habits, utilizing food sources as they become available. Periodic increases in availability of terrestrial and aquatic invertebrates from stochastic flooding events or hatches may have been an important factor in the evolution of feeding strategies of the species. Preference for terrestrial invertebrates and relatively uncommon taxa of aquatic invertebrates that are only sporadically available may reflect these strategies.

## A.12 Parasites

The majority of parasites of humpback chub are alien to the Colorado River Basin, introduced through nonnative fishes. Most notable are the external parasitic copepod, *Lernaea cyprinacea*, and the intestinal Asian tapeworm. During 1990–1993, *L. cyprinacea* was found on 8 of 6,294 fish from the Colorado River in Grand Canyon for an infection rate of only 0.13% and an average of 1.25 copepods (range, 1–2) per infected fish (Valdez and Ryel 1997). None of the infected fish showed signs of stress or illness, although open lesions had formed at some anchor points. This parasite infected 5.3% of humpback chub from the LCR (Hoffnagle et al. 2000). *Lernaea cyprinacea* was first reported from Grand Canyon in 1979 (Carothers et al. 1981) but has not become problematic because the mainstem fails to reach optimum maturation temperatures of 23–30°C (Bulow et al. 1979). *Lernaea* matures at temperatures as low as 18°C (Grabda 1963). In Black Rocks, Westwater Canyon, and Cataract Canyon, *L. cyprinacea* was found on 17% and 31% of juvenile and adult humpback chub, respectively during 1979–1981 (range, 1–13 copepods/infected fish; Valdez et al. 1982).

The internal Asian tapeworm was first reported from Grand Canyon in 1990 (Brouder and Hoffnagle 1997; Clarkson et al. 1997). During 1990–1993, this parasite was found in gut contents of 6 of 168 (3.6%) mainstem adult humpback chub treated with a nonlethal stomach pump, for an average of 6.7 tapeworms per infected fish (range, 1–28; Valdez and Ryel 1997). Clarkson et al. (1997) found Asian tapeworms in 28% of sacrificed humpback chub examined from the LCR in 1990–94. They also reported the parasite in intestines of common carp (*Cyprinus carpio*), fathead minnow (*Pimephales promelas*), speckled dace (*Rhinichthys osculus*), and plains killifish (*Fundulus zebrinus*). Brouder and Hoffnagle (1997) also found Asian tapeworms in humpback chub (22.5%) from the LCR in 1994, as well as in plains killifish (10.3%), speckled dace (3.8%), and fathead minnow (2.2%). They reported that nearly all (66.7–100%) of infected fish were captured near the LCR, although the parasite was found as far downstream as Kanab Creek, 132 km downstream of the LCR. During 1996–1997, the internal Asian tapeworm (*Bothriocephalus acheilognathi*) occurred in 31.6–84.2% of humpback chub examined in the LCR and 8.8–26.7% in the Colorado River (Hoffnagle et al. 2000); the crustacean (*Lernaea cyprinacea*) was found on 5.3–47.6% of chubs in the LCR and 0–6.7% in the Colorado River; the trematode (*Ornithodiplostomum sp.*) in 50%; and the nematode

(*Rhabodochona sp.*) in 5.3%. Markedly lower infestation rates of most parasites in the Colorado River in Grand Canyon demonstrate the detrimental effect of cold temperatures on most fish parasites of the Colorado River Basin. Infection of humpback chub by the Asian tapeworm is a concern because of possible stress and death to the host and widespread infestation during periods of stress. This parasite is able to complete its life cycle in the LCR where the temperature requirement of >20°C is met (Granath and Esch 1983), and although unable to complete its life cycle in the mainstem, it is apparently able to survive in a fish host in the cold temperatures. Meretsky et al. (2000) hypothesized that an observed decline in condition of adult humpback chub in Grand Canyon was a result of recent infestation by the internal Asian tapeworm.

A survey of diseases of endangered fishes in the Upper Colorado River Basin in 1981 (Flagg 1982) revealed that humpback chub carried the protozoans *Myxobolus* sp., *Apiosoma*, *Tetrahymena*, *Ambiphyra*, and *Chilodonella*; as well as the nematode *Philometra* sp., and the crustacean *Lernaea cyprinacea*.