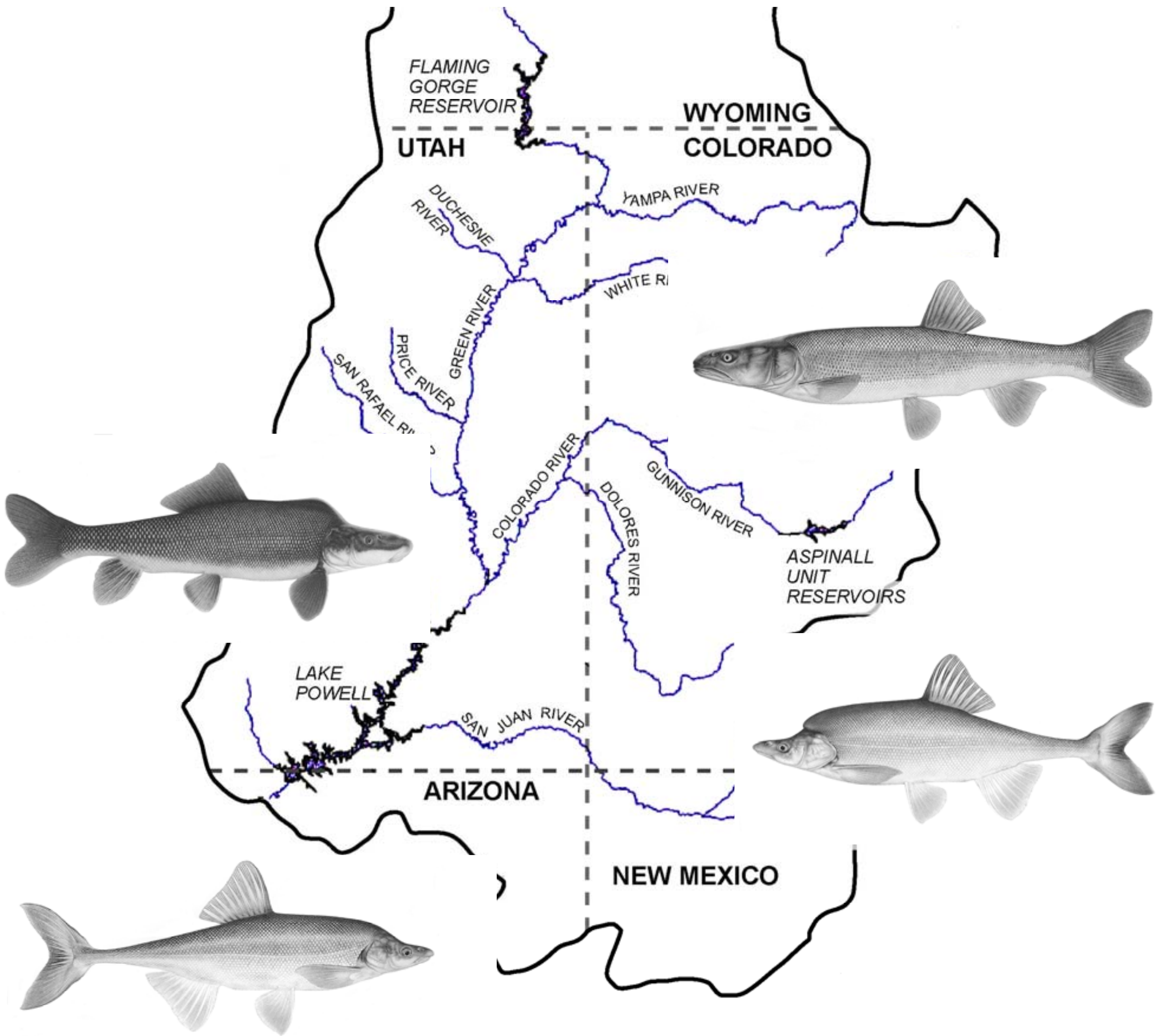
Research Framework for the Upper Colorado River Basin



Upper Colorado River Endangered Fish Recovery Program

U.S. Fish and Wildlife Service **April 28 2011**

Research Framework for the Upper Colorado River Basin

by

Richard A. Valdez
Ann M. Widmer

SWCA Environmental Consultants
172 West 1275 South
Logan, UT 84321
(435) 752-9606

and

Kevin R. Bestgen
Larval Fish Laboratory
Department of Fish, Wildlife, and Conservation Biology
Colorado State University
Fort Collins, CO 80523
(970) 491-1848

Tom Czapla, Program Coordinator

Upper Colorado River Endangered Fish Recovery Program
U.S. Fish and Wildlife Service
P.O. Box 25486
Denver Federal Center
Lakewood, Colorado 80225

Recovery Program Project 145

Recovery Program Final Report

April 28 2011

EXECUTIVE SUMMARY

The Upper Colorado River Endangered Fish Recovery Program (Recovery Program) coordinates recovery activities for the endangered Colorado pikeminnow (*Ptychocheilus lucius*), humpback chub (*Gila cypha*), razorback sucker (*Xyrauchen texanus*), and bonytail (*Gila elegans*) in the Upper Colorado River Basin. The Recovery Program was formed in 1988 and annually provides guidance for research, monitoring, and management actions through a Recovery Implementation Program Recovery Action Plan (RIPRAP). The RIPRAP was developed in 1996 as the Recovery Program's long range plan to identify specific activities and time frames required to recover the endangered fishes in the Upper Basin consistent with state and federal laws and compacts. The RIPRAP identifies activities and annual updates for research and management actions conducted in the Green, Yampa, Duchesne, White, Colorado, Gunnison, and Dolores rivers for five main program elements: Instream Flow Protection; Habitat Restoration; Nonnative Fish Management; Propagation and Genetics; and Life History, Monitoring and Research. The RIPRAP documents Program direction and accomplishments which facilitate continuation of the Recovery Program to provide Endangered Species Act compliance for projects undergoing Section 7 consultation.

The goal of the research framework project was to evaluate how well the activities identified under the RIPRAP address species threats and controlling factors. This need arose when declines of adult Colorado pikeminnow in the Green River subbasin and humpback chub in Yampa Canyon and Desolation/Gray Canyon were detected, and when abundance of razorback sucker and bonytail remained low. These trends prompted the Recovery Program to conduct this comprehensive assessment of its long-range planning to determine if certain aspects of the life history of the species and their controlling factors were being overlooked or not addressed, i.e., identify any gaps in research or management that were leading to the declines..

Estimates of population size for Colorado pikeminnow and humpback chub have become available for most populations only in the last decade, and the Recovery Program is beginning to develop a better understanding of population sizes and dynamics. Abundance estimates from 1992 to 2005 for Colorado pikeminnow in the Upper Colorado River showed an increase from 440 to 889 fish, a 102% increase. In the Green River, estimates of adult Colorado pikeminnow from 2000 to 2003 declined from over 4,100 in 2000 to 2,150 in 2003, a 48% decline. Analysis of data collected from 2006 to 2008 showed that abundance of adult Colorado pikeminnow rebounded, as numbers of adult fish in the Green River increased from about 2,450 to nearly 3,700. The variability of estimates suggested long-term population dynamics that are not fully understood and a need for continued reliable monitoring.

Estimates of humpback chub show similar intra and inter-population variability and long-term abundance dynamics are not well understood. Numbers of humpback chub have declined in the Yampa River and Desolation/Gray Canyon of the Green River; individuals from both populations are presently held in a hatchery. Population estimates of adult humpback chub in Black Rocks has fluctuated from a few hundred to almost a thousand during 1998–2008. Population estimates for humpback chub in Westwater Canyon averaged

4,737 adults in 1998-2000; 3,824 in 2003-2005; and 4,818 in 2007-2008. The Cataract Canyon population abundance averaged 345 adults in 2003-2005.
In recent years, only a few wild razorback sucker have been captured in the Upper Colorado River Basin and the estimated number of wild adults in the middle Green River was about 100 in 1999. In the Upper Colorado River, the numbers of razorback sucker captured have decreased dramatically since 1974 with very few wild adults remaining, prompting the Recovery Program to implement a hatchery augmentation program to build up numbers of fish in the wild. From 1995 to 2009, about 253,500 subadult and adult razorback sucker were stocked in the Upper Colorado River Basin. Based on a recent analysis of recapture data, hatchery-reared razorback sucker have relatively low survival. However, capture rates of razorback sucker larvae and adults are increasing and from 2007-2009 numbers of larvae captured were higher than at any time since sampling began in 1992, with the exception of 1994. This suggested successful acclimation of stocked fish, survival to adult life stage, and reproduction.

A similar stocking program has been implemented for bonytail since there are currently no self-sustaining populations in the wild. Since 1977, only 11 wild adults have been reported from the upper basin. From 2003 to 2009, about 94,000 subadult bonytail were stocked in the Upper Colorado River Basin. Sampling subsequent to stocking in the Green River downstream of the Yampa River indicated low persistence and poor survival of stocked bonytail. Stocked bonytail are being captured in other reaches through various sampling efforts and survival, growth, and movement are being assessed to improve the efficacy of hatchery augmentation.

As part of this research framework project, we cross-linked RIPRAP activities with controlling factors for each life stage of each of the four endangered fishes. Potential controlling factors were identified by development of conceptual life history models which illuminated biotic and abiotic factors that may limit various life stages of these species. We found overall that the comprehensive set of RIPRAP activities, organized under topical categories Instream Flow Protection, Habitat Restoration, Nonnative Fish Management, Propagation and Genetics, and Life History Monitoring and Research, addressed most of the biotic and abiotic factors that control each of the life history aspects of the four species.

Under instream flow protection, major research investigations have resulted in development and implementation of comprehensive flow recommendations for the Upper Colorado, Gunnison, Yampa, White, Green, and Duchesne rivers. Aspects of those flow recommendations continue to be evaluated to determine if endangered fish populations and their habitats are improving. The RIPRAP flow protection activities also include annual coordination by the Recovery Program for voluntary operation of selected reservoirs in the Upper Colorado River upstream from the confluence of the Colorado and Gunnison Rivers in order to enhance spring peak and summer base flows to improve endangered fish habitat in the 15-Mile Reach. Flows from Flaming Gorge Reservoir on the Green River and the Aspinall Unit on the Gunnison River are being managed to benefit the endangered fishes. Additional flow management activities occur in the Yampa River, where base flow supplementation occurs via releases from Elkhead Reservoir.

Habitat restoration actions have proceeded along several fronts and enhanced fish passage, screened diversion canals, as well as acquired and managed flood plain wetlands. Four fish passages have been constructed in the Upper Basin, allowing additional upstream access by fishes to about 150 km of historic habitat in the Gunnison and Upper Colorado rivers. Fish screens have been placed on three of the largest canals in the upper basin to minimize entrainment of fishes from mainstem populations. Screens are also being considered for Tusher Wash Diversion in the Green River and the Maybell Ditch in the Yampa River. A major research and management effort has also been implemented to acquire wetlands and restore flood plain wetland connectivity. Approximately 2,700 acres of floodplain are being managed along the Green, Colorado, and Gunnison rivers. Flood plain wetlands are thought important to enhance recruitment of razorback sucker in the Green River. Concentrations of potential toxicants—especially selenium and mercury—have been detected at relatively high levels at several locations in the Upper Basin, but effects of those constituents are poorly understood and activities are ongoing to ameliorate their effects. The Recovery Program promotes the following: continued monitoring, studies to determine effects to the endangered fish, and necessary remediation.

Nonnative fish management activities have been implemented throughout the Upper Basin. Activities include mechanical removal of target nonnative fish species, a Memorandum of Agreement implementing Procedures for Stocking Nonnative Fish Species, a Nonnative Fish Management Policy, and a Nonnative Fish Control Strategy for the Yampa River. Other studies also investigate provenance of fishes found in the river so off-channel or reservoir sources can be identified and controlled. Comprehensive analyses of existing fish removal data will provide additional guidance for future management actions. Flow management activities to disadvantage nonnative fishes are being implemented on an experimental basis. Densities of northern pike and smallmouth bass in portions of the Yampa River remain well above interim removal criterion, but declines in abundance and size structure changes suggest some positive effects.

Propagation activities are guided by recently developed and comprehensive stocking plans. From 2004 through 2009, about 175,000 subadult razorback sucker, 95,000 subadult bonytail, and 4,600 subadult Colorado pikeminnow were stocked in the Upper Colorado River Basin. The success of propagation activities and those stocking plans is being explicitly evaluated for razorback sucker and indirectly for bonytail, through sampling and recapture of stocked fish.

In addition, the Recovery Program administers numerous research and monitoring projects that provide a better understanding of the life history requirements of the four species, evaluate stocking success, and track the status of populations and progress toward recovery. Research and monitoring activities focus on sampling early life history stages of Colorado pikeminnow and razorback sucker, and juveniles and adults of all four species. Sampling allows inference regarding distribution and survival of stocked animals, and status and dynamics of wild populations and their offspring.

We identified several research needs that should be considered by the Recovery Program for incorporation into the RIPRAP (several of which are currently being investigated by ongoing studies). This research is needed to fill information gaps on controlling factors that require additional attention and include: understanding sources of mortality for age-0 and age-1 Colorado pikeminnow, humpback chub, and razorback sucker; development of more innovative techniques for evaluating the effectiveness of nonnative fish management; continued evaluation of effects of water pollutants, especially selenium, mercury, and pharmaceuticals [conducted outside the Recovery Program]; implementation of a climate change initiative that outlines a strategy for dealing with the effects of drought and reduced stream flow; an assessment of the potential and extent of hybridization by the white sucker on razorback, flannelmouth, and bluehead suckers; and continued annual assimilation and assessment of information on stocked razorback sucker and initiate an evaluation and assimilation of information on stocked bonytail.

We also identified several issues that individually or in combination may affect the efficacy of the Recovery Program. These issues are not unique to this program and are often difficult to address, but if recognized, can help to provide a framework that engenders greater cooperation and overall success. These include: database integration and utilization; consistency and training for research personnel; standardization of gear types; alternative nonnative fish management paradigms; weight of evidence approaches for making scientific inference; using population demographic information in an appropriate perspective; and recovery program limitations. An additional limitation may be the biology of the long-lived study species under investigation. For example, when this project was started razorback sucker reproduction in the Green River was low and adult Colorado pikeminnow abundance in the same basin was in serious decline. Since that time, reproduction by an increasingly large population of stocked razorback suckers has increased dramatically in the period 2007-2009 and recruitment of Colorado pikeminnow increased adult abundance by 2008 nearly to levels observed in 2000, a year when abundance was apparently as high as it has been since the inception of the Recovery Program in 1988. Those examples are particularly important because they occurred during periods of environmental stress induced by basinwide drought. We recognize that humpback chub abundance has declined and bonytail abundance remains low, but we also suggest that response of long-lived species to management actions is often difficult to measure and sometimes requires patience and a relatively long management and recovery timeline.

The recognition of those aforementioned issues by Recovery Program partners is important so that each party working independently and in cooperation can minimize their negative effects. The greatest information needs are a better understanding of the interaction of habitat and stream flow availability (e.g., age-0 pikeminnow backwater habitat, Green River connections with flood plain wetlands in spring), and the cumulative and interacting effects of nonnative fish and habitat on survival of early life stages of all four species. In general, we conclude that the RIPRAP provides a comprehensive basis for activities that are necessary to recover the four big river endangered fishes in the Upper Colorado River Basin.

TABLE OF CONTENTS

LIST OF TABLES

Table

LIST OF FIGURES

Figure

INTRODUCTION

Background

The Upper Colorado River Endangered Fish Recovery Program (Recovery Program) was established in 1988 to coordinate recovery activities for the endangered Colorado pikeminnow (*Ptychocheilus lucius*), humpback chub (*Gila cypha*), razorback sucker (*Xyrauchen texanus*), and bonytail (*Gila elegans*) in the Upper Colorado River Basin (Valdez and Muth 2005; Figure 1). Guidance for research, monitoring, and other activities is provided annually through a Recovery Implementation Program Recovery Action Plan (RIPRAP). Recovery goals for each of the four species (USFWS 2002a, 2002b, 2002c, 2002d) provide guidance to partners and stakeholders on management actions, recovery criteria, and cost and time necessary for recovery.

The Recovery Program implements management actions through the RIPRAP that are designed to remove or minimize effects of environmental stressors that threaten the endangered fish species. Activities identified in the RIPRAP provide guidance for prioritization and delineation of management actions and monitoring and research that are conducted by Recovery Program partners and stakeholders, as well as contractors under Recovery Program direction and administration. This research framework evaluates the effectiveness of RIPRAP activities identified annually under each of the Program's five primary recovery elements:

1. Instream flow identification and protection.
2. Habitat restoration.
3. Reduce nonnative fish and sportfish impacts.
4. Propagation and genetics management.
5. Research, monitoring and data management.

Need for this Project

The Recovery Program, with assistance from The Nature Conservancy and other environmental interests, identified the need for a research framework to track and link population monitoring with appropriate management actions through the concept of adaptive management. This need was perceived because annual population estimates of Colorado pikeminnow and humpback chub for 2000–2003 in the Green River subbasin showed a decline in numbers of adults. The cause for those declines was unknown but a better understanding of contributing factors is needed, i.e., identify any gaps in research or management that were leading to the declines. This report details the research framework project that 1) builds conceptual life history models of the endangered fish; 2) uses data specific to Colorado pikeminnow; and 3) forms linkages between species threats by life stages to past and ongoing RIPRAP activities.

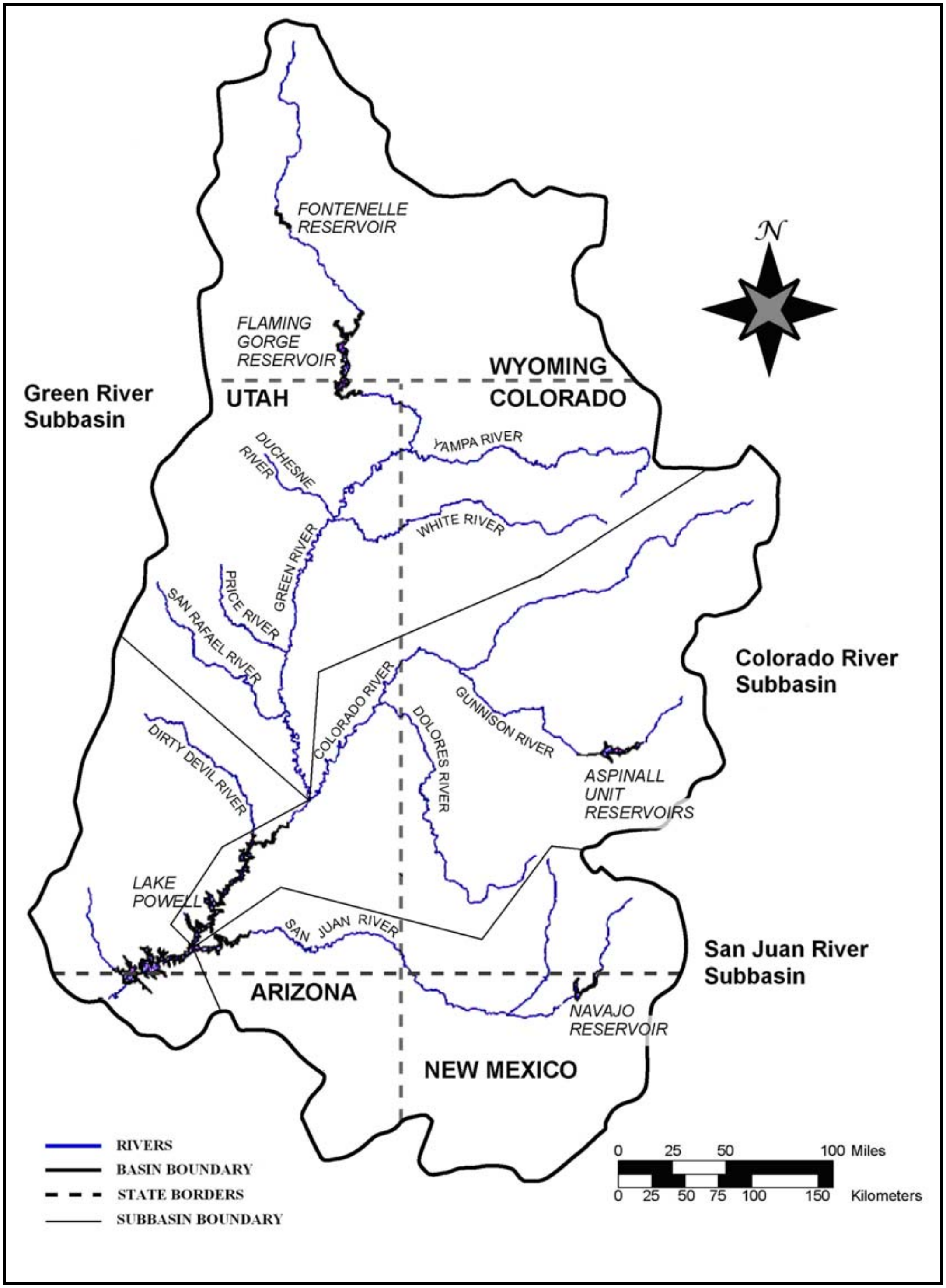


Figure 1. Map of the Upper Colorado River Basin and its subbasins. The Recovery Program coordinates recovery activities for the endangered fishes in the Upper Colorado River and Green River subbasins. Recovery activities in the San Juan River subbasin are coordinated by the San Juan River Basin Recovery Implementation Program.

Conceptual Approach

A Colorado pikeminnow conceptual model was developed that identified biotic and abiotic controlling factors by species life stage (Bestgen et al. 2006a). A need was identified for conceptual models by life stage for the other three species, in addition to identifying the sensitive life stages and the abiotic and biotic factors threatening those life stages. Information from activities conducted by the Recovery Program through the RIPRAP was evaluated to determine if they adequately addressed the threats to the life stages (Figure 2). If the threats are not adequately addressed, a research need was recommended to fill the information gap.

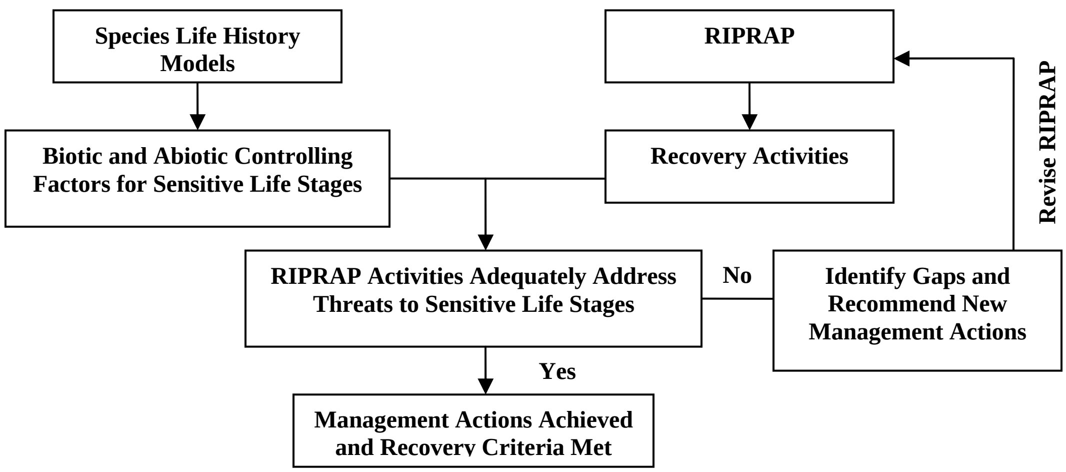


Figure 2. Conceptual approach for the research framework.

Purpose and Objectives

The purpose of this project is to evaluate how effectively RIPRAP activities address species threats. The objectives were to:

Objective 1: Develop conceptual life history models for each of the four endangered fish species.

Task 1-1.—Develop conceptual models.

A conceptual life history model is a diagrammatic representation of the life stages of a species and the linkages among the various life stages. Conceptual life history models help to provide a visualization of the inter-relationships of life stages, and the biotic and abiotic factors that control the population. An existing conceptual model for Colorado pikeminnow with biotic and abiotic controlling factors was updated to better understand factors that affect distribution and abundance of this species (Bestgen et al. 2006a). Similar conceptual models were also developed for humpback chub, razorback sucker, and bonytail. These models were developed from life history information gleaned from literature, ongoing research, and personal experiences (Bestgen et al. 1997, 2006b). These models illustrate important biotic and abiotic factors controlling recruitment of these species. Descriptions of population status, natural history, and controlling factors for each life stage are provided with each conceptual model to better integrate information and to aid reader understanding.

Objective 2: Link RIPRAP activities with species conceptual models in a hypothesis framework.

Task 2-1.—Identify monitoring programs in place to track resource responses and identify gaps.

Activities since the inception of the Recovery Program in 1988 were reviewed and evaluated to develop a history of research and monitoring programs that are ongoing, as well as discontinued to track responses by the four endangered fish species. The information for these programs was assimilated from past reports and publications. A history of research and monitoring programs will help to identify Recovery Program activities for following population status and trends, as well as evaluate the effects of management actions. This will also help to identify successful programs and how information is being used by the Recovery Program.

Colorado pikeminnow studies, monitoring activities, and management actions conducted within the Colorado and Green River basins were summarized in a Microsoft Access database. Database entries briefly summarized the methods and major findings or accomplishments of a study. A great deal of work has been done in the last 10 years for the benefit of the Colorado pikeminnow in the Upper Colorado River Basin, resulting in a large collection of reports. It can be viewed at http://www.swcageo.com/projects/denver/fws_cr/fwsmap.html. That database was central to understanding biology and management of Colorado pikeminnow and more importantly, the management actions undertaken to benefit native fishes.

Task 2-2.—Identify activities that address threats and information gaps.

Recovery Program reports and information were assimilated and used to evaluate how RIPRAP activities address primary controlling factors for the four endangered fishes identified in Task 1-1. The literature review consisted of information from 1999 through 2008 in the Upper Colorado River and Green River subbasins. Annual and final reports from the Recovery Program's web site (http://coloradoriverrecovery.org/documents-publications/work-plan-documents/project-annual-reports.html) were identified for the five primary program elements (see Introduction). Studies and monitoring activities (e.g., ISMP, drift netting, spring electrofishing, population estimates), as well as management actions (e.g., nonnative fish removal, flow management, fish passage) conducted by the Recovery Program were identified and evaluated to determine if these have been appropriately applied to species threats on life stages and in important river reaches.

Task 2-3.—Identify controllable and uncontrollable factors.

The overriding hypothesis of this work is that population dynamics of the four endangered fishes are determined by intrinsic and extrinsic factors that affect reproduction, survival, and recruitment of young, juveniles, and adults from year to year. These factors include environmental stressors that may limit population size and may be controlled through management actions (intrinsic); or these may be factors such as drought which are outside of the influence of management (extrinsic). These factors are categorized as controllable or uncontrollable.

STATUS OF FISH POPULATIONS

This section provides an overview of abundance for each of the endangered fish species and a description of important river reaches.

Overview of Abundance

Colorado Pikeminnow

Self-sustaining populations of Colorado pikeminnow occur in the Upper Colorado River and Green River subbasins. Sampling and adult abundance estimation from 1992 to 2005 for Colorado pikeminnow in the Upper Colorado River has increased from 440 to 889, a 102% increase (Table 1; Figure 3; Osmundson and White 2009). In the Green River, estimates of adult Colorado pikeminnow from 2000 to 2003 declined from around 4,100 in 2000 to 2,150 in 2003, a 48% decline. Sampling and analysis of data collected from 2006 to 2008 for adult Colorado pikeminnow population abundance in the Green River showed an increase in abundance from around 2,450 to nearly 3,700 adult fish (Table 1; Figure 4 *from* Bestgen et al. 2010 Table 10; Figure 8).

Table 1. Mark-recapture population estimates for Colorado pikeminnow in the upper basin.

Year	Upper Colorado	Green River	Year	Upper Colorado	Green River
1992	440	--	2002	--	2,772
1993	705	--	2003	661	2,142
1994	687	--	2004	668	--
1998	583	--	2005	889	--
1999	589	--	2006	--	2,454
2000	773	4,084[a]	2007	--	2,718
2001		3,304	2008	Not available yet	3,672

[a]adjusted for all of Green River subbasin (Yampa, White, Middle and Lower Green, Deso-Gray)

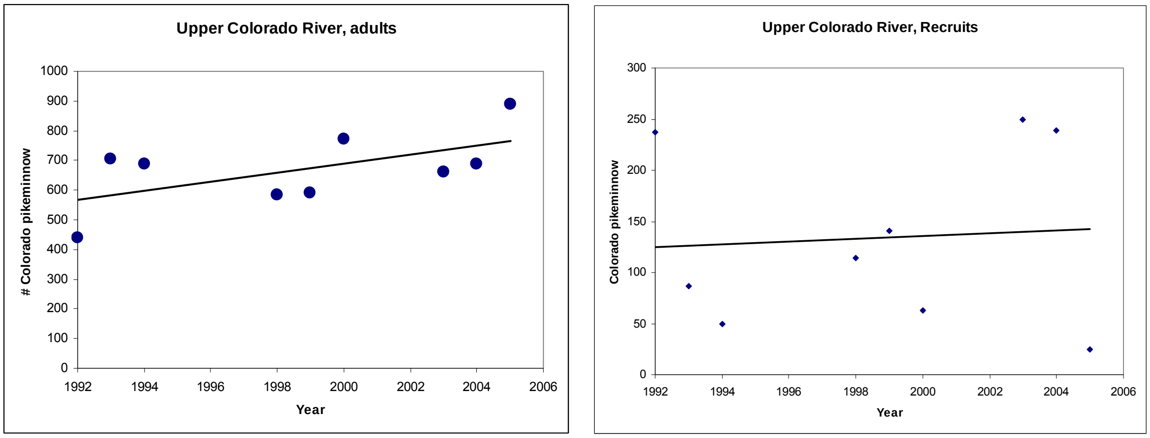


Figure 3. Estimated numbers of Colorado pikeminnow adults (≥ 450-mm TL) and recruits (400–449 mm TL) in the Upper Colorado River subbasin for 1992–1994, 1998–2000, and 2003–2005. Data from Osmundson and Burnham (1998), Osmundson (2000, 2003, 2004, 2005), and Osmundson and White (2009).

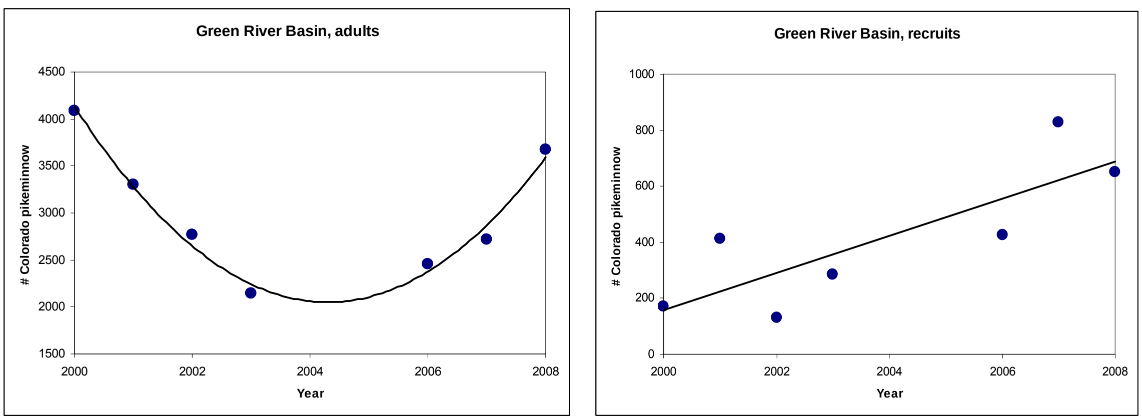


Figure 4. Estimated numbers of Colorado pikeminnow adults (≥ 450-mm TL) and recruits (400-449 mm TL) in the Green River subbasin (Yampa, White, Middle Green, Desolation-Gray Canyons, and Lower Green) for 2000–2003 and 2006–2008. For adults, the year 2000 estimate was expanded for the subbasin based on an estimate of 3,030 adults for the middle Green River and the White and Yampa rivers only. For subadults, the year 2000 estimate was for the middle Green River reach and the White and Yampa rivers only. Data from Bestgen et al. (2010).

Humpback Chub

There are five populations of humpback chub in the Upper Colorado River Basin. The Yampa River population is small, abundance is unknown, and declining catch rates resulted in capturing wild fish to create a refuge population to maintain genetic diversity. In addition, the Desolation/Gray canyons population has declined from a high of over 2,600 adults to a few hundred (Table 2; Jackson and Hudson 2005; Badame 2009), again causing the Recovery Program to bring individuals into captivity to maintain genetic diversity.

Population estimates of adult humpback chub in Black Rocks has fluctuated from a few hundred to almost a thousand during 1998–2008 (age 4+, ≥ 200 mm TL; McAda 2002, 2004, 2006: Francis and McAda 2010 (Table 2; Figure 5). Population estimates for humpback chub in Westwater Canyon averaged 4,737 adults in 1998–2000; 3,824 in 2003–2005; and 4,818 in 2007–2008 (Hudson and Jackson 2003; Jackson 2004; Elverud 2008). The Cataract Canyon population averaged 345 adults in 2003-2005 (Valdez and Badame 2005; Badame 2008).

Table 2. Mark-recapture population estimates for humpback chub in the four of the five upper basin populations.

Year	Westwater	Black Rocks	Deso/Gray	Cataract
1998	5,005	764	--	--
1999	4,234	921	--	--
2000	4,971	539	--	--
2001	--	--	1,254	--
2002	--	--	2,612	--
2003	3,288	478	937	468
2004	3,867	932	--	273
2005	4,317	--	--	295
2006	--	--	410	--
2007	5,696	345	204	--
2008	3,940	287	--	--

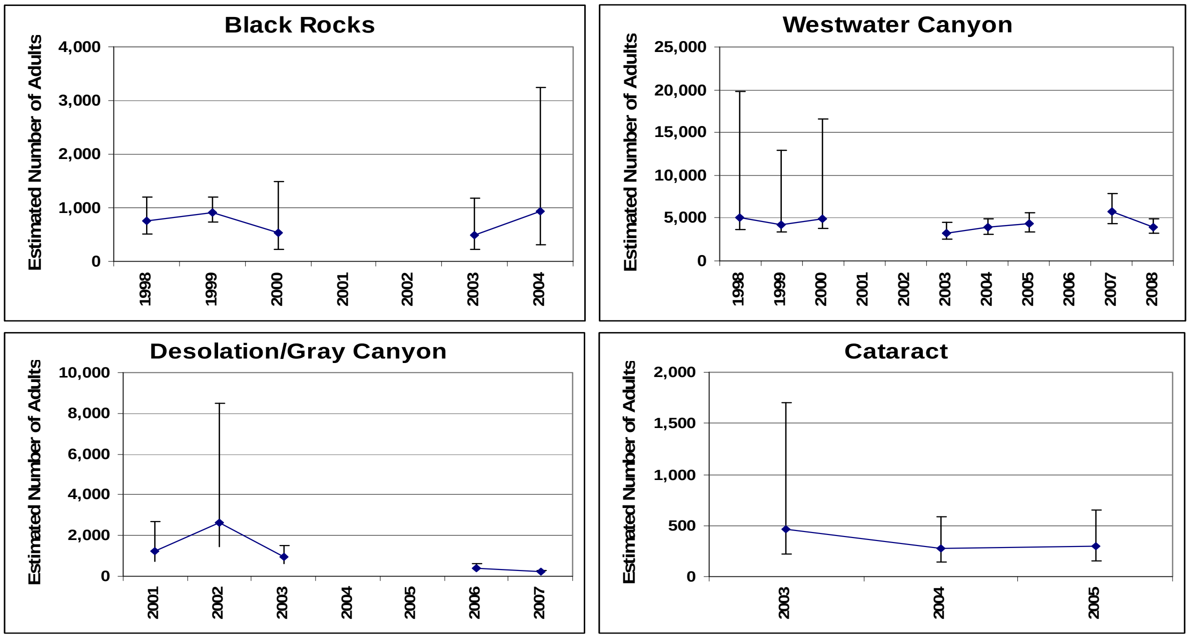


Figure 5. Population estimates of adult humpback chub (≥ 200-mm TL) in four of five populations of the Upper Colorado River Basin. Error bars are 95% confidence intervals. Data from Black Rocks (McAda 2002, 2004, 2006), Westwater Canyon (Elverud 2008), Desolation/Gray Canyon (pers. com., P. Badame, Utah Division of Wildlife Resources), and Cataract Canyon (Badame 2008).

Razorback Sucker

Historically, razorback suckers were widespread in the Upper Colorado River Basin in warm water stream reaches (Bestgen 1990). By the time endangered fish studies began around 1980 populations were apparently much reduced. Largest numbers of razorback sucker in the Upper Colorado River Basin were found in low gradient, flat-water reaches of the middle Green River between the Duchesne River and the Yampa River and in the Colorado River near Grand Junction (Tyus 1987; Bestgen 1990; Muth et al. 2000). Tag-recapture and telemetry data indicated that razorback sucker in the middle Green River constituted a single reproducing population (Modde and Irving 1998). Known spawning sites were located in the lower Yampa River and in the Green River near Escalante Ranch between river km 492 and 501 (distance upstream from Colorado River confluence), but other, less-used sites were probable (Tyus and Karp 1990; Modde et al. 1996; Modde and Irving 1998). Lanigan and Tyus (1989) estimated a middle Green River population of 948 adults (95% CI = 758–1,138). Eight years later, the population was estimated at 524 adults (95% CI = 351–696), and characterized as being stable or declining slowly with some evidence of recruitment (Modde et al. 1996). Through 1999, only a few individual razorback suckers were captured in the lower Green River; small numbers of larvae and juveniles indicate probable spawning in the vicinity of the San Rafael River confluence (Gutermuth et al. 1994; Chart et al. 1999; Muth et al. 2000; Bestgen et al. 2002). Data available were insufficient to estimate numbers of razorback sucker adults in the lower reach of the Green River (Minckley et al. 1991, Bestgen et al. 2002). Bestgen et al. (2002) estimated that the population of wild adult razorback sucker in the middle Green River was about 100.

In the Upper Colorado River subbasin, the number of razorback sucker captured decreased dramatically since 1974. The wild population was considered extirpated from the Gunnison River (Burdick and Bonar 1997) and there are only a few scattered adults in the mainstem Colorado River (Osmundson and Kaeding 1989). During a 2-year study (1979–1981), Valdez et al. (1982) captured only 52 individuals, all presumably old adults, in a 465–km reach of the Colorado River from Rifle, Colorado, to Hite, Utah. Between 1984 and 1990, only 12 individuals were captured in the Grand Valley despite intensive collecting efforts (Osmundson and Kaeding 1991). No young razorback sucker were captured anywhere in the Upper Colorado River from the mid-1960s to about 1990 (Osmundson and Kaeding 1991). The last wild razorback sucker was captured in the Upper Colorado River in 1995.

In an effort to bolster declining populations, the Recovery Program initiated stocking of razorback suckers in the Upper Colorado River Basin beginning in 1996 (Bestgen et al. 2002, Zelasko et al. 2009). Abundance estimates for razorback sucker were not available but capture-recapture studies suggest that some stocked fish survived (Zelasko et al. 2009, Table 3). Stocked razorback sucker had better survival when they were stocked in the fall, winter and spring and at larger sizes (Zelasko et al. 2009). The collection of larvae indicated that these stocked fish were behaving as wild fish and reproducing (Osmundson and Seal 2010). From 2004 through 2009, about 175,000 subadult razorback sucker have been stocked in the Upper Colorado River Basin. The number of recaptured stocked fish has been increasing since 1999 (Table 3), with more occurring during years when Colorado pikeminnow abundance estimation sampling was ongoing. This is true particularly since 2003, when relatively larger numbers of razorback sucker were available for recapture (Zelasko et al. 2009; K. Zelasko, unpublished data).

Table 3. Number of razorback sucker recaptured per year and river basin, 1997–2008 (modified after Zelasko et al. 2009, Zelasko unpublished data); recapture numbers in 2007-2008 were conservative as they represent only fish released since 2004. The arrow between 2003 and 2004 represents the time when a revised stocking plan was implemented that recommended stocking larger razorback sucker (≥ 300 mm total length). Yellow shaded numbers are years when population estimates for Colorado pikeminnow were occurring.

	Year						↓					
River Basin	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Colorado	0	1	0	24	31	3	157	121	361	15	32	314
Green	3	0	31	10	41	20	13	32	101	412	225	330

Bonytail

There are no self-sustaining populations of bonytail in the wild and only 11 wild, adult bonytail have been reported in the upper basin since 1979 (Valdez 1990; Kaeding et al. 1986). During 2004–2009, about 95,000 subadult bonytail have been stocked in the upper basin. Bonytail stocked in the Green River are being recaptured in canyon reaches (Valdez and Badame 2005) and survival of hatchery-reared bonytail is low as indicated by the low return rates of fish at large for more that 6 months (Bestgen et al. 2008). Bonytail have also been stocked in floodplain habitats and their survival continues to be evaluated (Modde and Haines 2005).

Important River Reaches

In order to link species threats by life stage with RIPRAP activities, it is necessary to understand the spatial distribution of various life stages of each species in the Upper Colorado River Basin. Some river reaches are far more important than others to particular life stages of a species, and it is important to ensure that appropriate studies are being allocated to these reaches. This project addresses RIPRAP activities in the Upper Colorado River and Green River subbasins; the San Juan River subbasin is not included.

Relative use of river reaches was previously determined by upper basin researchers through a Delphi process to establish priorities for geomorphology research (LaGory et al. 2003). Researchers identified river use for the Colorado pikeminnow, humpback chub, and razorback sucker, but felt that insufficient information was available for the bonytail. The Green River subbasin was divided into 12 longitudinal reaches and 5 tributaries; and the Upper Colorado River subbasin was divided into 15 reaches and 1 tributary. Relative use of these reaches by life stage for each of the three species is presented in the following sections. The color codes in Tables 3 to 5 correspond to the color codes in Figures 6 to 8, such that the cells in a single row of a table corresponds to the respective reach pie chart in the subbasin figure.

Colorado Pikeminnow

Important river reaches for Colorado pikeminnow are identified in Table 4 and illustrated for the Green River subbasin and the Upper Colorado River subbasin in Figure 6. In the Green River subbasin, the species is distributed throughout the mainstem from Lodore Canyon to the confluence of the Colorado River. It is also found in the Yampa and White rivers, with small numbers in the lower reaches of the Duchesne, Price, San Rafael, and Little Snake rivers. High use by most life stages is evident throughout much of the middle and lower Green River. There is high use of the White River by adults and subadults and use of the Yampa River for spawning and larval drift. The Green River from the mouth of the Yampa River downstream to the confluence of the Colorado River is an important corridor for drifting larvae and two reaches serve as important nursery areas for age-0 fish; i.e., Split Mountain to Desolation Canyon and Gray Canyon to the Colorado River confluence.

Colorado pikeminnow are found in the Upper Colorado River from just above the Price-Stubb Dam near Palisade to the Lake Powell inflow. Several dams and irrigation diversions just upstream of Grand Junction, Colorado, that prevented passage of Colorado pikeminnow into historic habitat since the early 1900’s have recently been modified to allow population expansion. Nonselective fish passage was completed at the Grand Valley Irrigation Company Diversion in 1998 and at the Price-Stubb Diversion in 2008, and selective fish passage was completed at the Redlands Diversion Dam in 1996 and at the Grand Valley

Project Diversion in 2005. Colorado pikeminnow are found in small numbers in the Gunnison River and in the lower Dolores River. Highest use by larvae, age-0, and subadults occurs in the lower reaches of the Upper Colorado River.

Table 4. Location and relative use of upper basin reaches by life stages of Colorado pikeminnow. Adopted from LaGory et al. (2003). 0 = no use (blank); 1 = little use (yellow); 2 = moderate use (orange); and 3 = high use (red).

River Reach	River Mile	Spawning	Dispersing Larvae	Juvenile (Age 0-1)	Subadult	Adult
I. Green River Subbasin						
Green River Mainstem						
1 Flaming Gorge Dam to Browns Park	396–410	0	0	0	0	0
2 Browns Park	362–396	0	0	0	0	1
3 Lodore Canyon	342–362	0	0	0	1	2
4 Yampa River to Island Park	334–342	0	3	0	2	3
5 Island and Rainbow Parks	326–334	0	3	1	2	3
6 Split Mountain Canyon	319–326	0	3	1	2	3
7 Split Mountain Canyon to Desolation Canyon	216–319	0	3	3	2	3
8 Desolation and Gray Canyons	132–216	3	3	2	3	3
9 Gray Canyon to Labyrinth Canyon	92–132	0	3	3	3	3
10 Labyrinth and Stillwater Canyons	0–92	0	3	3	3	3
Green River Tributaries						
11 Yampa River–Above Yampa Canyon	45–129	0	0	0	1	3
12 Yampa River–Yampa Canyon	0–45	3	3	1	2	2
Little Snake River	–	0	0	0	0	1
Duchesne River	–	0	0	1	2	2
White River	–	0	0	1	3	3
Price River	–	0	0	0	1	1
San Rafael River	–	0	0	1	1	1
II. Upper Colorado River Subbasin						
Colorado River Mainstem						
1 Rulison to DeBeque Canyon	204–232	0	0	0	0	0
2 DeBeque Canyon to Palisade	185–204	0	0	0	0	0
3 Palisade to Gunnison River	171–185	1	1	1	1	3
4 Gunnison River to Loma	154–171	3	3	1	1	3
5 Loma to Westwater Canyon	125–154	3	3	1	1	2
6 Westwater Canyon	113–125	0	3	1	1	1
7 Cottonwood Wash to Dewey Bridge	94–113	3	3	1	1	2
8 Dewey Bridge to Hittle Bottom	88–94	0	3	2	1	1
9 Hittle Bottom to White Rapid	78–88	2	3	1	1	1
10 White Rapid to Jackass Canyon	70–78	0	3	1	1	1
11 Jackass Canyon to Moab Bridge	64–70	0	3	3	2	1
12 Moab Bridge to Green River	0-64	0	3	3	3	1
13 Green River to Lake Powell	-14–0	0	2	3	2	1
Colorado River Tributaries						
14 Gunnison River–Hartland Dam to Roubideau Cr.	58–66	0	0	0	0	1
15 Gunnison River–Roubideau Cr. to Colorado River	0–58	2	2	0	0	2
Dolores River	–	0	0	0	0	1

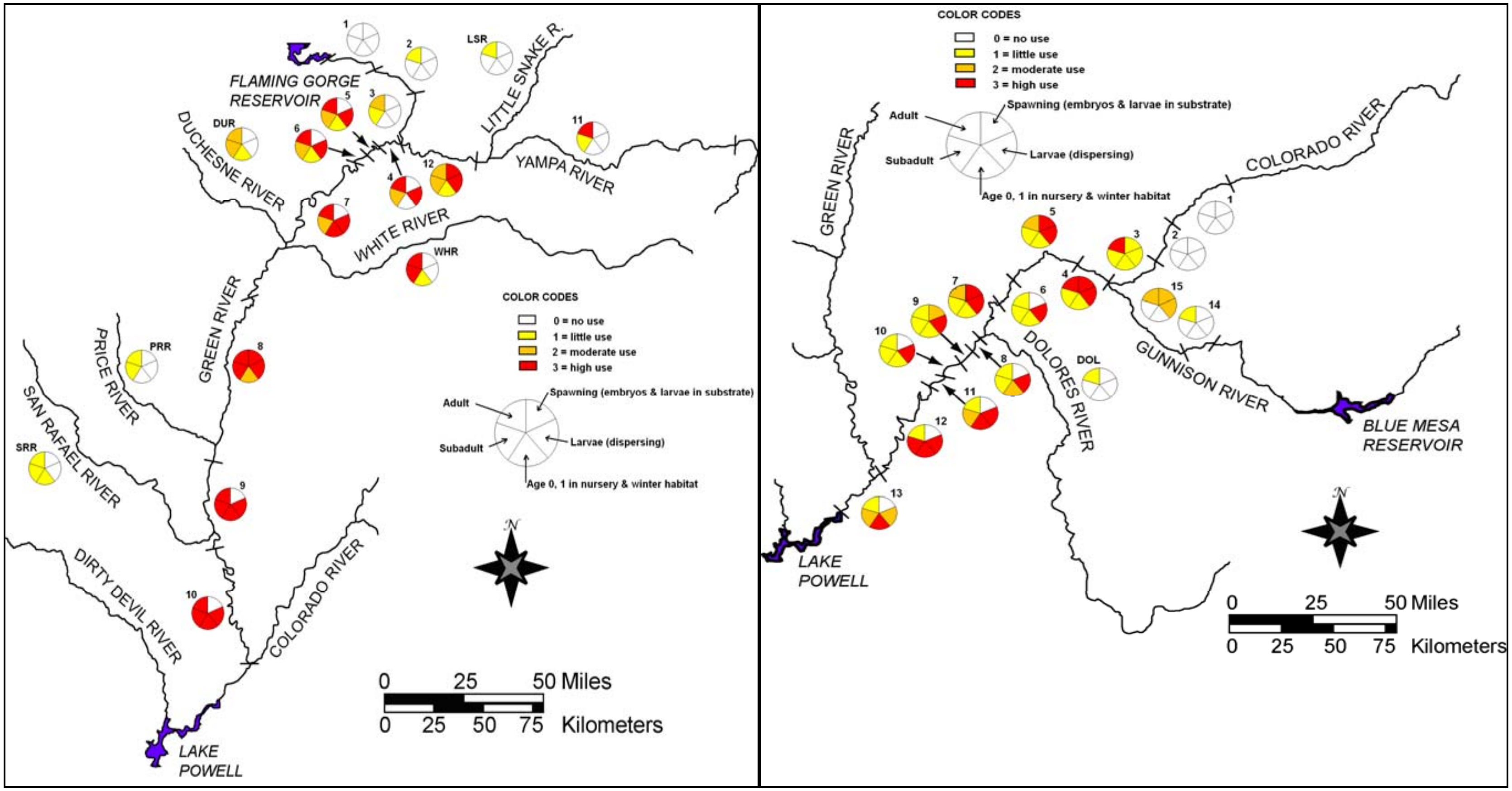


Figure 6. Location and relative use of Green River subbasin reaches (left) and Upper Colorado River subbasin reaches (right) by life stages of Colorado pikeminnow. See Table 3 above for relative use ratings.

Humpback Chub

Important river reaches for humpback chub are identified in Table 5 and illustrated for the Green River subbasin and the Upper Colorado River subbasin in Figure 7. Moderate to high use areas correspond to the five upper basin populations. In the Green River subbasin, a small population occurs in the lower Yampa River and extends into Whirlpool Canyon of the Green River, with individuals occasionally found in Split Mountain Canyon. A second population is located in Desolation/Gray canyons of the Green River, where individuals are found at varying concentrations in an 135-km reach of river.

In the Upper Colorado River subbasin, highest use areas for humpback chub correspond to Black Rocks, Westwater Canyon, and Cataract Canyon. Although population centers occur in Black Rocks and Westwater Canyon, numerous individuals have been marked and recaptured moving from one population to the other. A few individuals are also sometimes caught in the reach between the two populations. These populations are spaced about 16 km apart.

The population in Cataract Canyon is located primarily from the first rapid in Cataract Canyon to just upstream of the last rapid. However, the level of Lake Powell has receded in the last 10–15 years and scouring of old lake sediments continues to expose some of the rapids of Cataract Canyon that may provide additional habitat for the species and may allow for a downstream expansion of the population.

Few humpback chub are found in areas outside of these population centers. Evidently, newly-hatched larvae do not drift long distances and are rarely found very far from their natal areas. Also, adults have a high fidelity for specific river reaches that populations tend to remain in the same canyon-bound reaches. Occasionally, individual fish are found outside of these population centers, or individuals are found in areas that may have supported historic populations. For example, suspected humpback chub were found in the Beavertail Bend of DeBeque Canyon in the late 1970's, and recently individuals have been captured at the fish passage structure at the Grand Valley Project Diversion (implemented in 2005). This suspected aggregation of humpback chub was not acknowledged by the researchers during the Delphi process and does not appear in Table 4 or in Figure 7.

Table 5. Location and relative use of upper basin reaches by life stages of humpback chub. Adopted from LaGory et al. (2003). 0 = no use (blank); 1 = little use (yellow); 2 = moderate use (orange); and 3 = high use (red).

River Reach	River Mile	Spawning	Dispersing Larvae	Juvenile (Age 0-1)	Subadult	Adult
I. Green River Subbasin						
Green River Mainstem						
1 Flaming Gorge Dam to Browns Park	396–410	0	0	0	0	0
2 Browns Park	362–396	0	0	0	0	0
3 Lodore Canyon	342–362	0	0	0	0	0
4 Yampa River to Island Park	334–342	1	1	1	1	1
5 Island and Rainbow Parks	326–334	0	0	0	0	0
6 Split Mountain Canyon	319–326	1	1	1	1	1
7 Split Mountain Canyon to Desolation Canyon	216–319	0	0	0	0	1
8 Desolation and Gray Canyons	132–216	3	3	3	3	3
9 Gray Canyon to Labyrinth Canyon	92–132	0	0	0	0	0
10 Labyrinth and Stillwater Canyons	0–92	0	0	0	0	0
Green River Tributaries						
11 Yampa River–Above Yampa Canyon	45–129	0	0	0	0	1
12 Yampa River–Yampa Canyon	0–45	2	2	2	2	2
Little Snake River	–	0	0	0	0	1
Duchesne River	–	0	0	0	0	0
White River	–	0	0	0	0	0
Price River	–	0	0	0	0	0
San Rafael River	–	0	0	0	0	0
II. Upper Colorado River Subbasin						
Colorado River Mainstem						
1 Rulison to DeBeque Canyon	204–232	0	0	0	0	0
2 DeBeque Canyon to Palisade	185–204	0	0	0	0	0
3 Palisade to Gunnison River	171–185	0	0	0	0	0
4 Gunnison River to Loma	154–171	0	0	0	0	0
5 Loma to Westwater Canyon-Black Rocks	125–154	3	3	3	3	3
6 Westwater Canyon	113–125	3	3	3	3	3
7 Cottonwood Wash to Dewey Bridge	94–113	0	0	0	0	0
8 Dewey Bridge to Hittle Bottom	88–94	0	0	0	0	0
9 Hittle Bottom to White Rapid	78–88	0	0	0	0	0
10 White Rapid to Jackass Canyon	70–78	0	0	0	0	0
11 Jackass Canyon to Moab Bridge	64–70	0	0	0	0	0
12 Moab Bridge to Green River	0-64	0	0	0	0	0
13 Green River to Lake Powell-Cataract C.	-14–0	2	2	2	2	2
Colorado River Tributaries						
14 Gunnison River–Hartland Dam to Roubideau Cr.	58–66	0	0	0	0	0
15 Gunnison River–Roubideau Cr. to Colorado River	0–58	0	0	0	0	1
Dolores River	–	0	0	0	0	0

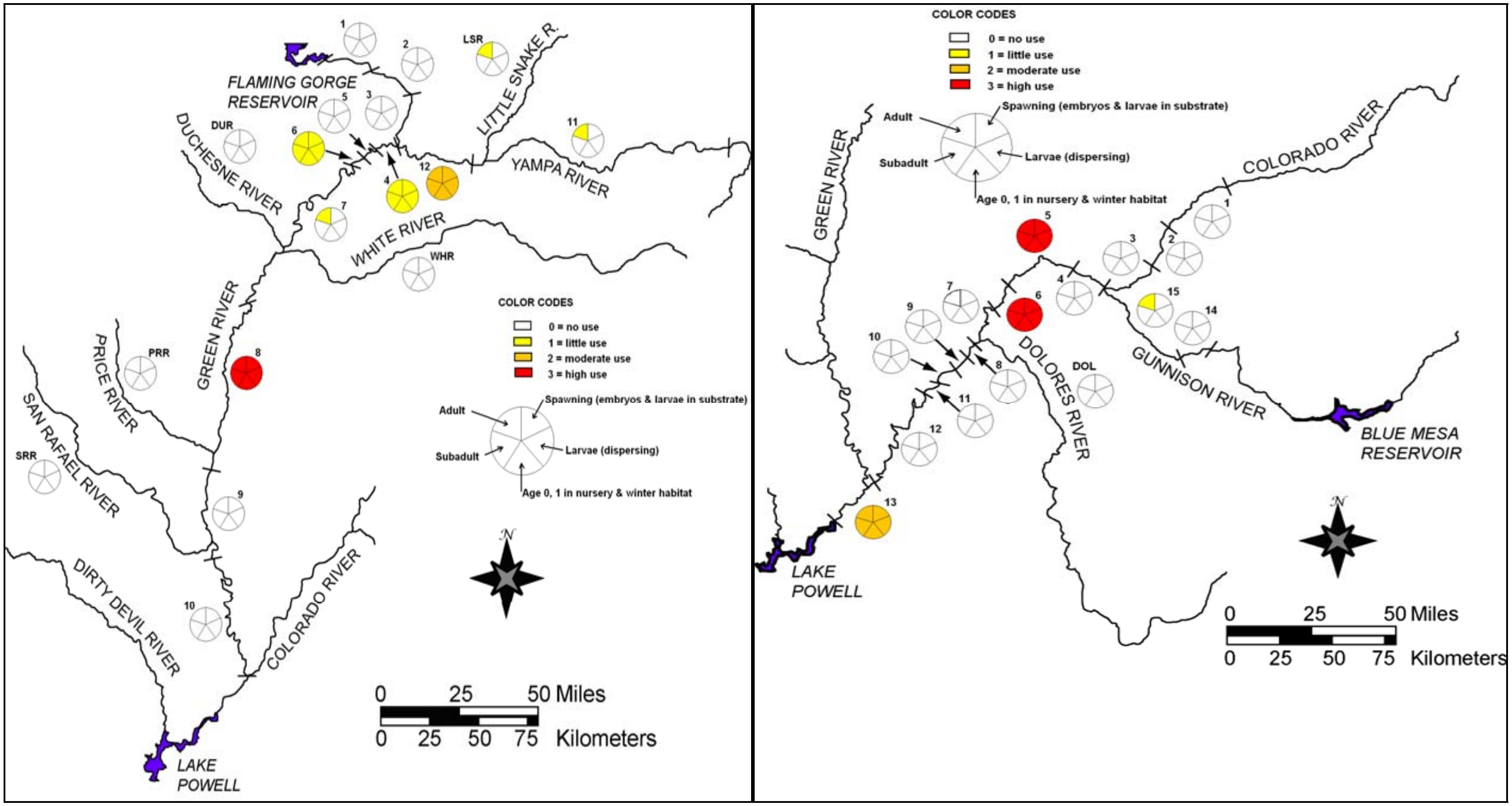


Figure 7. Location and relative use of Green River subbasin reaches (left) and Upper Colorado River subbasin reaches (right) by life stages of humpback chub. See Table 4 above for relative use ratings.

Razorback Sucker

Important river reaches for the razorback sucker are identified in Table 6 and illustrated for the Green River subbasin and the Upper Colorado River subbasin in Figure 8. The only area of high use by all life stages is in the Split Mountain Canyon to Desolation Canyon reach, where most available floodplains are located that are important nursery habitats for this species. The only two known spawning bars for razorback sucker are located at the upper end of this reach; i.e., near the southern boundary of Dinosaur National Monument. Individual larvae, subadults, and adults have been found from the mouth of the Yampa River downstream to Split Mountain Canyon.

Small numbers of individuals have also been found downstream of Desolation/Gray Canyon to the confluence of the Colorado River. Larvae and age-0 fish have been found in various reaches of the Green River. Larvae and age-0 razorback sucker found downstream of the Price and San Rafael rivers were likely produced in the area based on presence of ripe adults (in part, Bestgen et al. 2002) and presence of larvae earlier in the year than in the middle Green River.

In the Upper Colorado River subbasin, the species was found from Rulison downstream to Lake Powell, but numbers throughout have declined and wild individuals are rare. Most individuals captured are from recent and ongoing hatchery releases. Although the Price-Stubb Dam had been a barrier to upstream movement by razorback sucker, remnant individuals were found downstream of Rulison. Passage structures have been installed at the Grand Valley Irrigation Company Diversion, Price-Stubb Diversion, and Grand Valley Project Diversion that will allow upstream expansion of the population.

The most recent occurrence of razorback sucker in the Upper Colorado River is in the Grand Valley upstream and downstream of the Gunnison River. The channel in this reach is lined with natural and artificial floodplains used by razorback sucker as nurseries and for resting by adults. Most life stages have been found in the Gunnison River, and drifting larvae indicate successful spawning in that tributary. The Redlands fish passage on the lower Gunnison River allows razorback sucker access to and from the Gunnison River.

Table 6. Location and relative use of upper basin reaches by life stages of the razorback sucker. Adopted from LaGory et al. (2003). 0 = no use (blank); 1 = little use (yellow); 2 = moderate use (orange); and 3 = high use (red).

River Reach	River Mile	Spawning	Dispersin g Larvae	Juvenile (Age 0-1)	Subadult	Adult
I. Green River Subbasin						
Green River Mainstem						
1 Flaming Gorge Dam to Browns Park	396–410	0	0	0	0	0
2 Browns Park	362–396	0	0	0	0	0
3 Lodore Canyon	342–362	0	0	0	1	1
4 Yampa River to Island Park	334–342	1	2	0	2	2
5 Island and Rainbow Parks	326–334	0	2	0	2	2
6 Split Mountain Canyon	319–326	1	2	0	2	2
7 Split Mountain Canyon to Desolation Canyon	216–319	3	3	3	3	3
8 Desolation and Gray Canyons	132–216	1	1	0	2	2
9 Gray Canyon to Labyrinth Canyon	92–132	2	3	3	1	1
10 Labyrinth and Stillwater Canyons	0–92	0	3	3	1	1
Green River Tributaries						
11 Yampa River–Above Yampa Canyon	45–129	0	0	0	0	0
12 Yampa River–Yampa Canyon	0–45	2	2	0	1	1
Little Snake River	–	0	0	0	0	0
Duchesne River	–	1	1	1	2	2
White River	–	0	0	0	1	1
Price River	–	0	0	0	0	0
San Rafael River	–	0	3	3	1	1
II. Upper Colorado River Subbasin						
Colorado River Mainstem						
1 Rulison to DeBeque Canyon	204–232	3	0	0	0	3
2 DeBeque Canyon to Palisade	185–204	0	0	0	1	1
3 Palisade to Gunnison River	171–185	3	0	0	0	3
4 Gunnison River to Loma	154–171	3	0	0	0	3
5 Loma to Westwater Canyon-Black Rocks	125–154	0	0	0	0	1
6 Westwater Canyon	113–125	0	0	0	0	0
7 Cottonwood Wash to Dewey Bridge	94–113	0	0	0	0	0
8 Dewey Bridge to Hittle Bottom	88–94	0	0	0	0	0
9 Hittle Bottom to White Rapid	78–88	0	0	0	0	0
10 White Rapid to Jackass Canyon	70–78	0	0	0	0	0
11 Jackass Canyon to Moab Bridge	64–70	0	0	0	0	0
12 Moab Bridge to Green River	0-64	1	0	0	0	0
13 Green River to Lake Powell-Cataract C.	-14–0	0	0	0	0	0
Colorado River Tributaries						
14 Gunnison River–Hartland Dam to Roubideau Cr.	58–66	1	1	0	1	1
15 Gunnison River–Roubideau Cr. to Colorado River	0–58	1	1	0	1	1
Dolores River	–	0	0	0	0	0

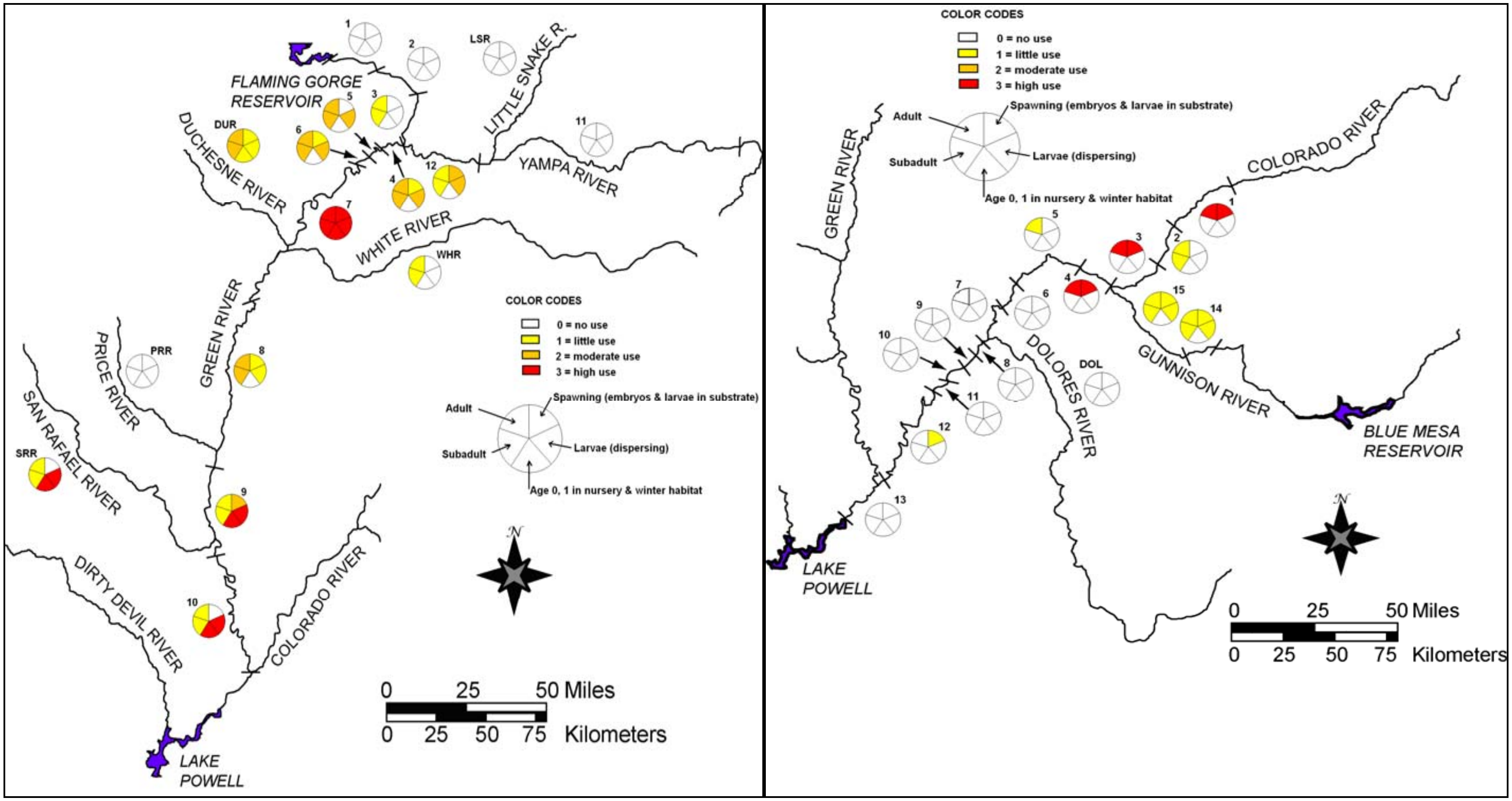


Figure 8. Location and relative use of Green River subbasin reaches (left) and Upper Colorado River subbasin reaches (right) by life stages of the razorback sucker. See Table 5 above for relative use ratings.

CONCEPTUAL LIFE HISTORY MODELS

General Conceptual Model Description

Conceptual life history models for the Colorado pikeminnow, humpback chub, razorback sucker, and bonytail are presented in the following respective sections for each species. The boxes depicted in each of the conceptual models represent either developmentally discrete events or life stages that occupy similar habitat and hence, may be affected by a similar set of limiting factors. The arrows connecting the boxes show the logical development sequence and inter-relationships among life stages. Separate biotic and abiotic limiting factors are presented that affect abundance and survival of each species and life stage, recognizing that some of the most important limiting factors likely represent interactions among two or more factors.

The models convey an annual temporal life history structure that begins with development of embryos in the substrate. Several compartments in the life-history model detail factors limiting the early life stages of these species. This structure was not intended to imply that early life stages are more important than juveniles or adults. Rather, this was done to underscore the dramatic changes in physical ability and environmental requirements that early life stages of fish undergo. In addition, because of their small size and limited energetic reserves, early life stages are susceptible to a greater variety of harsh conditions and controlling factors compared to juvenile and adult fish.

Some later life stages were combined either because they have similar habitat and limiting factors (e.g., large juveniles and adults), or because their life history requirements and controlling factors were poorly understood (e.g., larvae to juveniles for razorback sucker, age-0, age-1 Colorado pikeminnow in winter habitat). The models end with variable-sized cohorts of adult fish. However, the models should not be viewed as terminating with adults, but instead represent a continuous life history cycle, because abundance of adults affects the quantity and quality of embryos that begins each annual cycle. The sum of annual production cycles reflects the current distribution, abundance, and status of the respective species.

Colorado Pikeminnow

Embryos and Larvae in Substrate

The conceptual model for Colorado pikeminnow (Figure 9) is divided into five main stages, which emphasize early life history stages. Adults spawn in summer following spring runoff and a number of biotic controlling factors affect reproductive success and survival of embryos and larvae (Haynes et al. 1984; McAda and Kaeding 1989; Tyus and Haines 1991; Bestgen 1996; Bestgen and Williams 1994). The number and condition of adults in the population, as well as their age and size structure, are critical to egg production and successful reproduction by this aggregate, broadcast spawner (Osmundson et al. 1997, 1998). Predation on embryos and larvae by sympatric fish species and possibly insect larvae may occur, but has not been documented. Also, physical disturbance of spawning sites by other fish may displace incubating eggs or larvae.

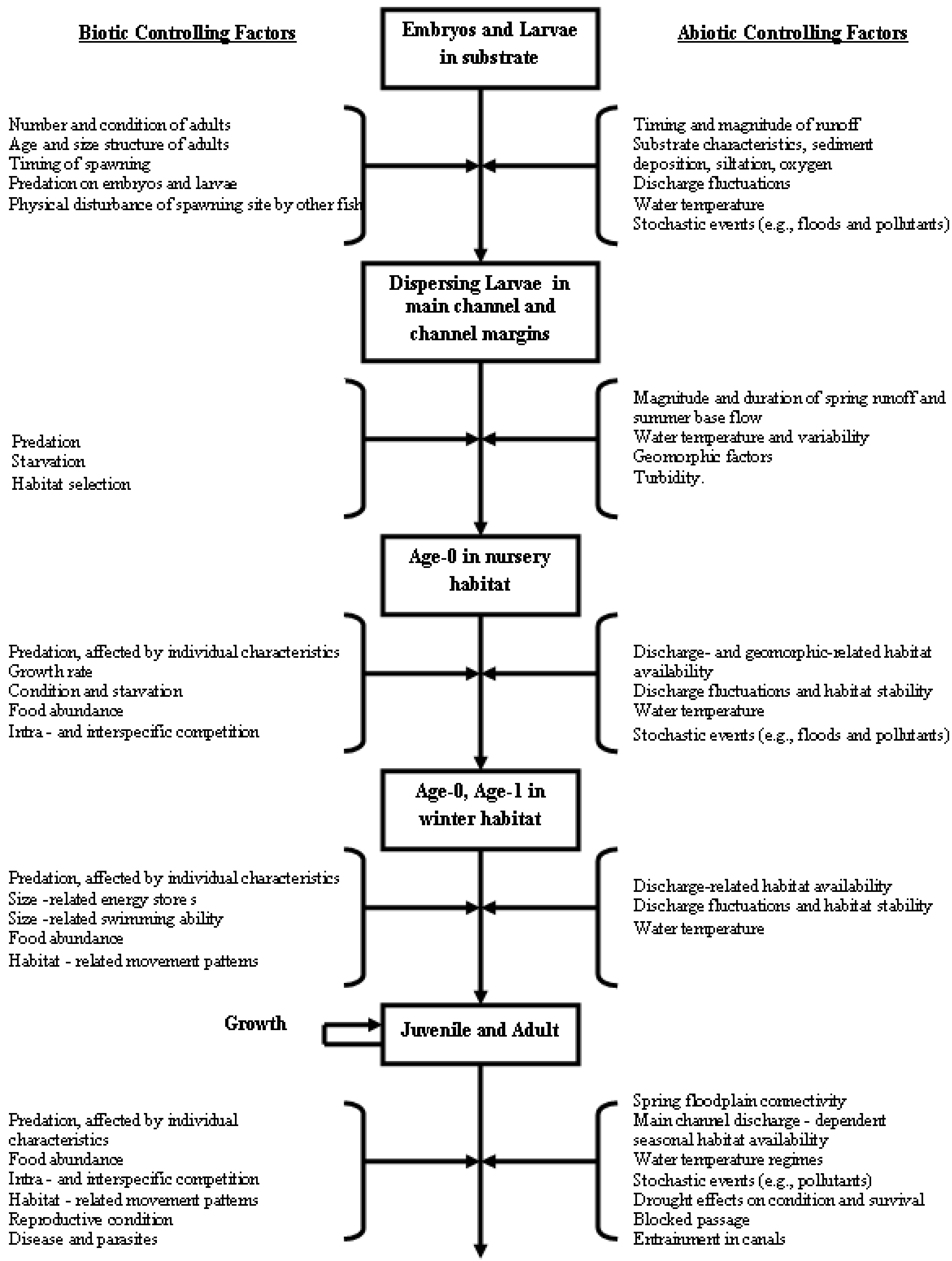


Figure 9. Colorado pikeminnow conceptual model.

Several abiotic controlling factors also influence survival of embryos and larvae of Colorado pikeminnow. The timing and magnitude of runoff, as well as water temperatures, are important factors that influence conditions of spawning sites and timing of reproduction. Embryos of Colorado pikeminnow incubate in stream gravels that are deposited during high spring flows (Nesler et al. 1988; Harvey et al. 1993), and natural flow regimes with high peaks are thought important to cleanse and rebuild gravel bars used for spawning. Substrate characteristics, sediment deposition, siltation, and oxygen levels all affect survival of embryos. Also, stochastic events (e.g., floods and pollutants) can suddenly and dramatically affect survival of embryos and larvae.

Dispersing Larvae in Main Channel and Channel Margins

Larvae of summer-spawning Colorado pikeminnow drift downstream after hatching and occupy low-velocity channel margins and backwater habitats. Drifting larvae are less than 10 mm long and their survival is dependent on entrainment in nursery backwaters before their yolk sac is absorbed and starvation sets in. Predation during drift, but particularly in nursery backwaters, can be substantial by a suite of nonnative fish species.

Survival of dispersing larvae is also influenced by a number of abiotic controlling factors. The magnitude and duration of spring runoff and summer base flows are important because peak and antecedent flows are needed to build and sustain nursery backwaters. Water temperature and variability can influence growth and size of individuals entering a stressful winter period when energy reserves are critical (Thompson et al. 1991). Geomorphic factors in the river channel that influence the location and extent of backwater development can greatly affect nursery habitat availability. Also, turbidity can provide cover for young Colorado pikeminnow from predators during this highly susceptible life stage.

Age-0 in Nursery Habitat

Biotic controlling factors that affect age-0 Colorado pikeminnow in nursery backwaters include predation affected by individual characteristics, growth rate, condition and starvation, food abundance, and intra- and inter-specific competition. Abiotic controlling factors include discharge and geomorphic related habitat availability, discharge fluctuations and habitat stability, water temperature, and stochastic events (e.g., floods and pollutants).

Colorado pikeminnow provide a good example of the complex interactions that exist in nature and are portrayed in the conceptual model. A biotic factor, predation, interacting with abiotic factors including water temperature and streamflow fluctuations may influence growth and survival of early life stages (Bestgen et al. 1997, 2006a). Warm, productive conditions enhance growth and survival of young Colorado pikeminnow while high turbid flows reduce growth. Reduced growth may extend the window of susceptibility of early life stages to predation by small-bodied predators such as red shiners (Rupert et al. 1993). The combined effect of reduced growth caused by abiotic factors interacting with the biotic factor predation may have reduced year-class strength of age-0 Colorado pikeminnow (Haines and Tyus 1990; Bestgen et al. 1997, 2006a). Abundance of Colorado pikeminnow at this life stage appears to be positively linked to later recruitment of juveniles and adults (Osmundson and White 2009; Bestgen et al. 2010). Factors that influence creation of backwater habitat, and biotic interactions of age-0 pikeminnow and non-native fishes is poorly understood but studies are ongoing to better understand this process (Bestgen et al. 2006a, synthesis study FR-BW).

Age-0, Age-1 in Winter Habitat

Outcomes of complex interactions among these controlling factors have implications that carry forward into other life stages and seasons. Variable summer conditions produce cohorts of age-0 fish in autumn of varying abundance and size, factors that may affect overwinter survival. For example, even though relatively small and slow-growing Colorado pikeminnow can survive to autumn, small-bodied juveniles may have relatively low overwinter survival (Haines et al. 1998; Bestgen et al. 2006a). In a laboratory study, Thompson et al. (1991) found that both fed and starved Colorado pikeminnow that were relatively small (mean TL of 30 or 36 mm) had lower survival than larger fish (mean TL of 44 mm) over simulated winter conditions.

In a Green River field study, Haines et al. (1998) found that small Colorado pikeminnow (modal TL of 28 mm) had only 6% overwinter survival during a high-flow winter period. In a different year when Colorado pikeminnow were larger (>38-mm TL), they had higher overwinter survival (56 to 65%), however, winter flows were lower. Poor overwinter survival of small Colorado pikeminnow in the Green River places added importance on the fewer larger fish from early cohorts that survive the summer, because those may have higher overwinter survival (Bestgen et al. 2006a). Thus, the complexity of factors that control distribution and abundance of Colorado pikeminnow at each life stage are closely linked.

Juvenile and Adult

Understanding recruitment variation of age-0 and older fish is critical to understand recruitment of cohorts of large juveniles and adults in later years in both the Upper Colorado River and Green River subbasins. This is especially important because strength of recruitment year-classes of late-maturing Colorado pikeminnow may be set many years prior. Ongoing studies are exploring biotic and abiotic aspects of recruitment variation of Colorado pikeminnow (e.g., project 138, FR-BW) and may shed light on processes that should receive management priority.

Predation by non-native fishes is an ongoing concern for maintenance of native fish populations in the Upper Colorado River Basin, and for Colorado pikeminnow, may affect all life history stages. Effects of hypothesized red shiner predation on recruitment of early life stages of Colorado pikeminnow and other species have been investigated (Ruppert et al. 1993; Bestgen et al. 2006a). Expanding populations of smallmouth bass and other centrarchids in nursery habitat reaches of the Upper Colorado River and the middle Green River may negatively affect early life stages as well as juveniles. Large northern pike are documented predators on adult life stages of Colorado pikeminnow in the Yampa River (pers. comm. J. A. Hawkins, Colorado State University).

A number of abiotic factors affect Colorado pikeminnow populations. Spring floodplain connectivity is important for large juveniles and adults as spring habitat for feeding and accumulation of temperature degree days for gonadal maturation. Main channel discharge and water temperature regimes determine seasonal habitat availability and are critical for habitat quality during summer and winter periods of low flow and rigorous environmental conditions. Stochastic events may suddenly and dramatically affect the population; e.g., oil spills have occurred near spawning sites. Periods of drought can affect the entire riverine ecosystem and directly and indirectly impact Colorado pikeminnow populations by affecting habitat, food availability, and condition of individuals. Mainstem dams and diversions have impeded movement of adults for many years and blocked populations from historic habitat (Tyus 1990; Irving and Modde 2000). Often, canals associated with these dams entrain individuals of all sizes and effectively remove them from the population.

Humpback Chub

The conceptual model for humpback chub (Figure 10) is divided into five main stages, which emphasize early life history stages. Limiting factors information for humpback chub is not well-known, particularly for early life history stages. Lack of information about that life stage, which is mostly based on the inability to identify young chubs to species, limits assessment of factors that influence year-class strength and subsequent recruitment and abundance dynamics of adults. The extent of identification difficulties for young of Yampa River *Gila* were recently summarized by Snyder et al. (2006), but pertain to all humpback chub populations in the Upper Colorado River Basin. The following describes each life history stage and the respective controlling factors:

Embryos and Larvae in Substrate

Humpback chub spawn shortly after the peak of spring runoff at water temperatures of 16-22°C (Valdez and Clemmer 1982; Kaeding et al. 1990). Aggregations of adults release and fertilize eggs in rubble, cobble, and gravel substrates along channel margins or on large submerged mid-channel bars. The eggs incubate in interstitial spaces and hatch in about 5 days, and the larvae remain for several days before drifting short distances to shallow, protected shoreline habitats. Several biotic factors influence populations. Number and condition of adults are important to reproduction where multiple spawners must gather to fertilize eggs that are broadcast over cobbles and gravels. The age and size structure of adults determines the number of eggs that can be released by a given female and can help to determine year-class strength. Predation on embryos and larvae probably occurs but has not been documented.

Several abiotic controlling factors also affect humpback chub populations. Timing and magnitude of runoff can influence habitat conditions and temperature for reproduction and incubation of eggs; although there is evidence that humpback chub can spawn in a wide range of flows and temperatures (Valdez and Clemmer 1982; Gorman and Stone 1999). Substrate characteristics, sediment deposition, siltation, and oxygen in spawning cobbles and gravels are critical factors for survival of embryos and larvae; e.g., high sediment and low oxygen can suffocate embryos. Discharge fluctuations can strand or desiccate incubating

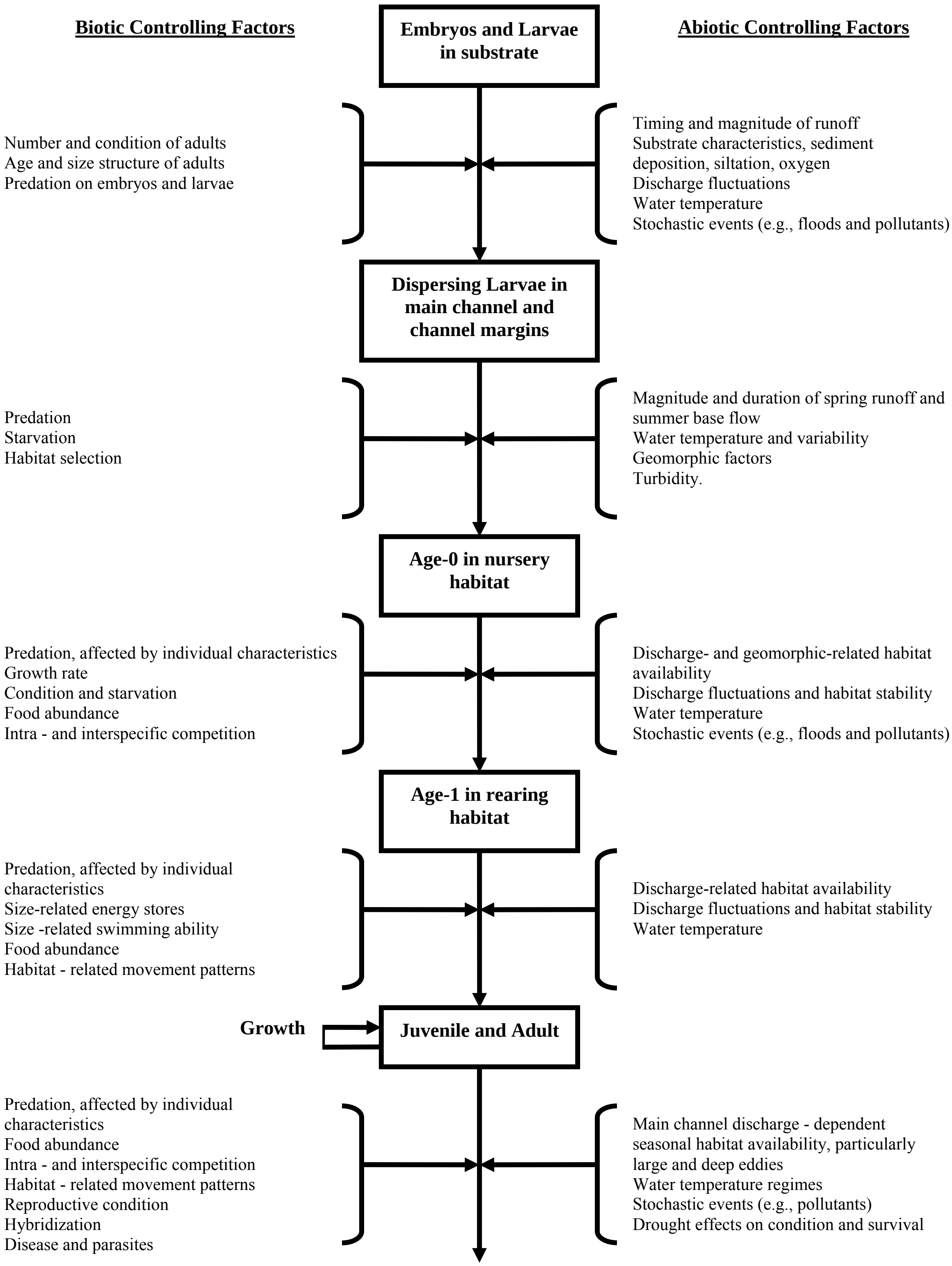


Figure 10. Humpback chub conceptual model.

eggs or kill larvae, and stochastic events (e.g., floods and pollutants) can kill large numbers of adults and severely reduce population viability. Heavy rainfall over landscapes with recently applied fire retardant has resulted in floods with large kills of fish in at least one of the six populations.

Dispersing Larvae in Main Channel and Channel Margins

Humpback chub larvae do not appear to drift great distances. All six known populations are restricted to relatively small areas of river and larvae are rarely found downstream of these populations. Larvae are commonly found along warm sheltered shoreline habitats, and they may be found in backwaters although these habitat features are rare in canyon reaches and particularly during spring runoff when the larvae are emerging.

Biotic controlling factors for this life stage include predation, starvation, and habitat selection. Predation by nonnative fish can be high on newly emerged larvae, and starvation may be significant if the larvae are unable to find suitable productive habitats for feeding before their yolk sacs are absorbed.

Age-0 in Nursery Habitat

Young-of-year humpback chub continue to use shallow, warm, productive, sheltered habitats that they entered as larvae. They may use backwaters if available, although this habitat feature is not common in canyon-bound reaches where population centers occur. Backwaters are used by young humpback chub in Grand Canyon where these features are warm refuges from cold mainstem releases through Glen Canyon Dam.

A major controlling factor of humpback chub populations is predation on young by a variety of nonnative fish species. Cold water temperature, such as in Grand Canyon, slows growth rates of these young fish and renders them susceptible to predation for extended time periods. Food availability and abundance are critical to growth, condition, and survival of these young fish. Intra- and inter-specific competition can be severe in the shallow habitats used by these fish, particularly by nonnative species.

Important abiotic controlling factors include discharge and geomorphic-related habitat availability, discharge fluctuations and habitat stability, water temperature, and stochastic events (e.g., floods and pollutants). Survival of young humpback chub is critical to year-class strength and eventual recruitment to the adult portion of the population. The physical condition of their habitat is important and instability in that habitat can displace fish from feeding areas and make them susceptible to predation.

Age-1 in Rearing Habitat

Humpback chub in their second year of life (i.e., age-1) tend to continue to occupy the same shallow, sheltered shoreline habitats as in their first year of life. However, these fish occupy deeper water and move to explore other habitats. Biotic controlling factors are several including predation by larger predators and the need to find sufficient food to maintain energy stores. Swimming ability affects their ability to compete and escape predators, and cold water temperatures can significantly reduce their swimming ability (Valdez and Ryel 1995).

Important abiotic controlling factors include discharge-related habitat availability, discharge fluctuations and habitat stability, and water temperature. As with biotic factors, habitat integrity is important for the survival of these young fish. Although a wide range of flows can be tolerated by the age-1 fish, flow changes that significantly reduce sheltered shoreline habitat can detrimentally affect habitat availability; e.g., flow changes that cause shoreline habitats to change from talus slopes to steep vertical walls or sandy beaches (Converse et al. 1998).

Juvenile and Adult

Humpback chub dramatically shift habitat use in their second or third years of life and move from shallow, sheltered shorelines to large mid-channel recirculating eddies. These eddies provide large entrainment zones for food and low velocity regions for resting (Valdez and Hoffnagle 1999).

Biotic factors that affect humpback chub populations include predation, food abundance, intra- and inter-specific competition, habitat related movement patterns, reproductive condition, hybridization, and disease and parasites. Predation affects primarily the smaller juveniles because there are few large sympatric predators capable of ingesting an adult humpback chub. Large numbers of nonnative fishes implies considerable competition for space and food, although not many other fish species occupy the large recirculating eddies. Invasion of canyon reaches by roundtail chub (*Gila robusta*) during periods of low flow allows for increased incidence of hybridization between these closely related species (Dowling and DeMarais 1993).

Abiotic controlling factors for humpback chub include main channel discharge and effects on seasonal habitat availability, particularly large and deep eddies; water temperature regimes; stochastic events (e.g., pollutants); and drought effects on condition, survival, and invasion of occupied habitats by other fish species. Adult humpback chub are uniquely suited to live in the swift canyon reaches of the Colorado River System. High spring flows create severe hydrologic conditions that preclude most other fish species from these habitats, but prolonged year-around low flows and periods of drought can break down these isolating mechanisms and disrupt food production and allow for invasion by competing or hybridizing fish species.

Razorback Sucker

The conceptual model for the razorback sucker (Figure 11) is divided into four main stages, which emphasize early life history stages. Limiting factors for razorback sucker are reasonably well understood and the most important involve recruitment failure at early life stages (Minckley 1983; Bestgen 1990; Modde et al. 1996; Bestgen et al. 2002; Marsh et al. 2003). The following describes each life history stage and the respective controlling factors.

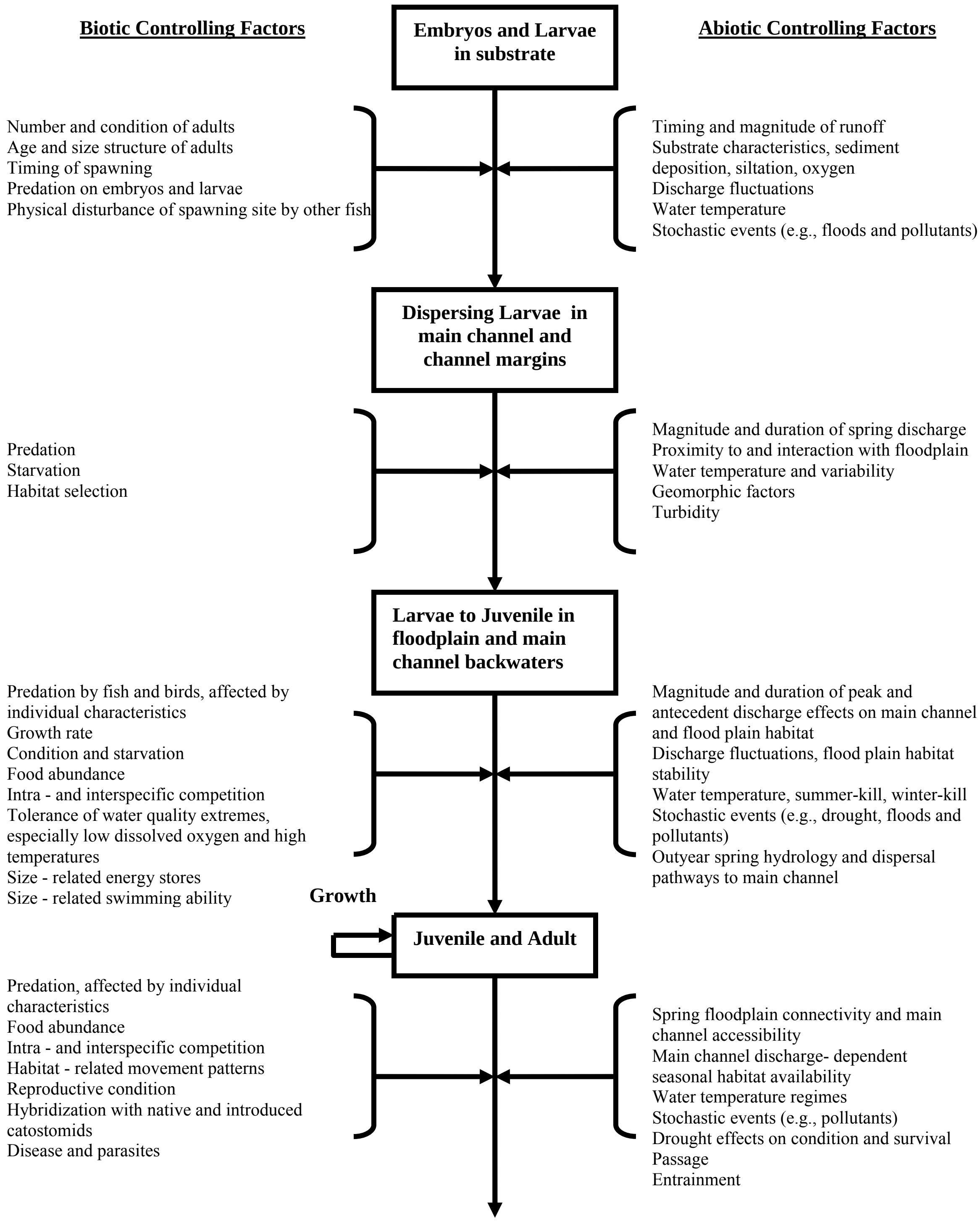


Figure 11. Razorback sucker conceptual model.

Embryos and Larvae in Substrate

Razorback sucker appear to spawn over specific spawning bars of cobble and gravel. Biotic controlling factors for this life stage of the razorback sucker include number and condition of adults, age and size structure of adults, timing of spawning, predation, and physical disturbance of spawning sites by other fish. The number and condition of adults and their age and size structure are the most critical factors. Low population size limits reproduction from few fish on spawning bars, and old or young individuals limit the numbers of eggs produced and their survival.

Abiotic controlling factors include timing and magnitude of runoff; substrate characteristics, sediment deposition, siltation, oxygen; discharge fluctuations; water temperature; and stochastic events (e.g., floods and pollutants). Physical and chemical conditions on spawning bars are important to the survival of embryos and larvae, and can be determined by antecedent flows and flows at the time of spawning.

Dispersing Larvae in Main Channel and Channel Margins

Dispersal of razorback sucker larvae from spawning bars occurs during high spring runoff flows. Biotic controlling factors include predation, starvation, and habitat selection. These small drifting larvae must find productive floodplains in a few days before starvation, and the floodplain habitats used as nurseries often also have large numbers of predaceous fishes. Abiotic factors include magnitude and duration of spring discharge, proximity to and interaction with floodplains, water temperature and variability, geomorphic factors, and turbidity. The relationship between river flow and floodplain connection is important to drifting larvae to ensure that the larvae become entrained in food-rich habitats.

Larvae to Juvenile in Floodplain and Main Channel Backwaters

This appears to be the most critical life stage for the razorback sucker. Biotic controlling factors include predation by fish and birds, growth rate, condition and starvation, food abundance, intra- and inter-specific competition, tolerance of water quality extremes especially low dissolved oxygen and high temperatures, size-related energy stores, and size-related swimming ability. Abiotic factors include magnitude and duration of peak and antecedent discharge effects on main channel and flood plain habitat; discharge fluctuations; flood plain habitat stability, water temperature, summer-kill, winter-kill; stochastic events (e.g., drought, floods and pollutants); and outyear spring hydrology and dispersal pathways to the main channel.

Restoration efforts for razorback sucker in the Upper Colorado River Basin focus mainly on remediation of physical habitat alterations and reduction of negative effects of introduced fishes. Specifically, predation on early life stages of razorback sucker, combined with slow growth, is thought a primary effect of non-native fishes that limits recruitment (Minckley et al. 1991; Mueller 2006). In the Upper Colorado River Basin, flow reduction due to storage of spring runoff, and effects of channelization and levee placement, reduce frequency and duration of floodplain inundation. Programs have been established to re-connect important floodplain habitat with the river main stem during spring peak flows. This is designed to entrain razorback sucker larvae into warm, food-rich floodplain areas, which are likely important as rearing and resting habitat for early and life adult stages of spring-spawning razorback sucker, and may enhance recruitment (Modde et al. 1996; Muth et al. 1998; Bestgen et al. 2002). Recruitment in cold, food-poor, and high-velocity main channel habitat in spring is thought low in most years. Occasional drying to reset the fish communities of floodplain wetlands is thought important to reduce predator loads and enhance recruitment (Christopherson et al. 2005; Valdez and Nelson 2004). Thus, a main factor limiting razorback sucker recruitment and recovery is related to floodplain wetland habitat availability, which is controlled by spring flow levels.

Juvenile and Adult

Biotic controlling factors include predation, food abundance, intra- and inter-specific competition, habitat-related movement patterns, reproductive condition, hybridization with native and introduced catostomids, and disease and parasites. Abiotic factors include spring floodplain connectivity and main channel accessibility, main channel discharge and dependent seasonal habitat availability, water temperature regimes, stochastic events (e.g., pollutants), drought effects on condition and survival, passage, and entrainment.

In addition to habitat related recruitment problems, predation by non-native fishes on razorback sucker has been documented and may be a concern for all life history stages. Predation on early life stages of catostomids in backwaters by red shiner has been documented and doubtless also occurs in floodplain wetlands that are dominated by non-native fishes (Ruppert et al. 1993; Modde 1996; Modde and Haines 2005; Christopherson et al. 2005). Predation by northern pike on larger stocked razorback sucker has also been documented (pers. comm., K. Christopherson, Utah Division of Wildlife Resources). Expanding populations of smallmouth bass and northern pike in reaches where razorback sucker reproduce or are stocked may further limit their recruitment. Expanding populations of white sucker also pose a threat to razorback sucker via hybridization. White sucker readily hybridize with native flannelmouth and bluehead suckers in the Yampa River and the Green River in Lodore Canyon. Downstream expansion of white sucker into reaches where razorback sucker are attempting to reproduce, such as the middle Green River and portions of the Upper Colorado and lower Gunnison rivers, should be monitored and managed to prevent hybridization.

Bonytail

The conceptual model for bonytail (Figure 12) is divided into four main stages, which emphasize early life history stages. This life history model structure conveys discrete life history stages and differences among their physical abilities and factors that affect them, so far as can be hypothesized given the sparse information available regarding bonytail ecology in a natural setting. The following describes each life history stage and the respective controlling factors.

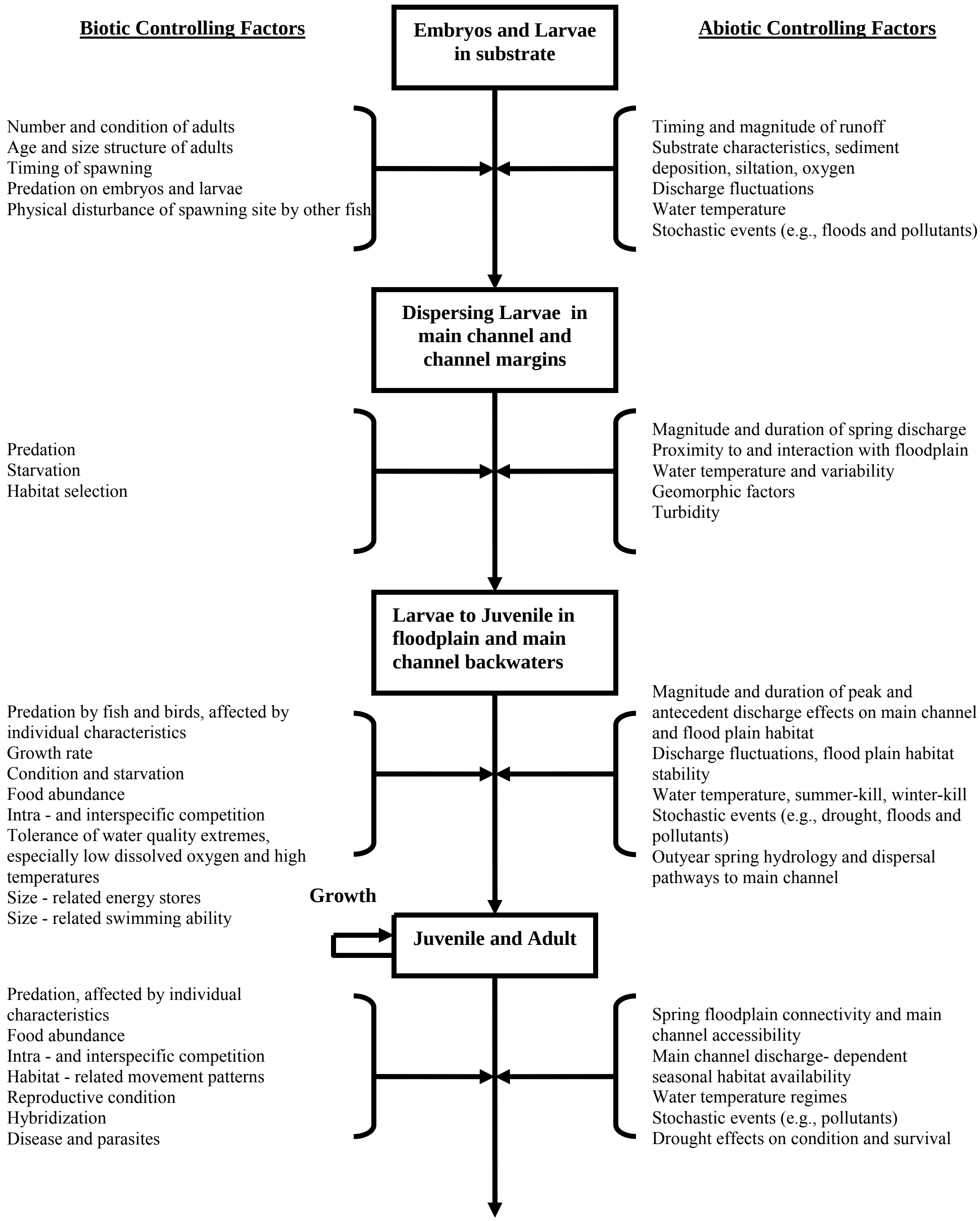


Figure 12. Bonytail conceptual model.

Embryos and Larvae in Substrate

No information is available on the ecology of early life stages of bonytail in the wild, thus, we can only speculate on factors important to survival of young bonytail based on other species in the basin. Poor survival of adult bonytail in the wild suggested that additional studies are needed to understand habitat needs of this species. Newly implemented flow and temperature recommendations from Flaming Gorge Dam, which attempt to restore aspects of a more natural flow regime, may improve habitat for bonytail (Muth et al. 2000).

Dispersing Larvae in Main Channel and Channel Margins

Larval bonytail are rarely found in the wild and their drift and dispersal modes remain unknown. The biotic and abiotic factors that affect this life stage are presumed to be similar to those for the razorback sucker.

Larvae to Juvenile in Floodplain and Main Channel Backwaters

Larval bonytail are rarely found in the wild. Hatchery-reared larvae and juveniles have been release into natural floodplains and survival is low primarily because of predation by nonnative fish. The biotic and abiotic factors that affect this life stage are presumed to be similar to those for razorback sucker.

Juvenile and Adult

Spawning in the wild has not been documented for bonytail, and the important characteristics of spawning sites are not known. The species is known to spawn unassisted in small outdoor earthen holding ponds in hatcheries, and it is surmised that spawning may occur in floodplain habitats in spring. The biotic and abiotic factors that affect this life stage are presumed to be similar to those for the razorback sucker.

Discussion of Conceptual Models

Despite the uncertainty in our understanding of recruitment processes of Colorado pikeminnow, bonytail, humpback chub, and razorback sucker, the life-history models provide an efficient means of organizing and presenting the current state of knowledge. The models also encourage a process-oriented view of recruitment and of potential controlling environmental factors. Unfortunately, our ability to conceptualize and hypothesize about recruitment far exceeds our ability to quantitatively describe this process.

The life-history models were based on recent literature, ongoing research, and our personal experiences. Researchers who are familiar with the four fish species will find some parts of the life-history models useful, but may disagree with the importance of other components. We encourage critical review of the models because other researchers will undoubtedly have different knowledge and perspectives regarding factors that influence recruitment of these species.

We advocate that the life-history models be used as a foundation for future investigations and hope they will serve as a useful tool for developing and testing hypotheses related to factors that control recruitment. Over time, the life-history model should be revised as gaps in life history knowledge are identified and studied, and alternative hypotheses are supported or refuted. For example, the age-0 and age-1 life stage of Colorado pikeminnow in the model in winter habitat may be divided into separate model components if future studies suggest a basis for doing so. This evolution of the life-history model is consistent with the scientific basis of endangered fish research in the Colorado River System, and adaptive management of endangered fish populations.

The models also reflect that distribution and abundance patterns of various life stages of the four fish species in a natural setting change temporally and spatially each year (Bestgen et al. 1997; Bestgen et al. 2006a). Furthermore, the conceptual models illustrate that multiple and interacting biotic and abiotic factors could potentially affect each life stage of each species on different time scales. For example, predation, habitat selection, and stochastic events are factors that affect survival and growth on a daily basis. On a larger temporal scale, number of age-0 fish that survive to autumn may be a function of the number of larvae produced, their growth rates, predator density, quantity and quality of backwaters available that summer, and stochastic events. Differences in abiotic or biotic conditions among years may also promote year-classes of different strengths for different species. For example, conditions that promote a strong year-class of razorback sucker may not necessarily produce a good recruitment year for Colorado pikeminnow or humpback chub.

These complex life history models also obviate the need for holistic and long-term thinking about processes that affect recruitment and outcomes of potential management actions. Recognition and understanding of various temporal scales is also important because it emphasizes that recruitment to a life stage is a function of numerous processes occurring at different times and that in order to explain characteristics of a population it might be necessary to study events that occurred days, months, years, or even decades ago. For example, reduced recruitment of age-0 Colorado pikeminnow in Green River nursery habitat reaches in the mid- to late-1990s was thought to influence reduced abundance of adult life stages in the period 2000 to 2003 (Bestgen et al. 2005).

The extended temporal aspect of life-history patterns of these endangered fishes suggests that detectable changes in population structure may not occur until well into the future. Similarly, this temporal aspect of endangered fish life histories should be considered when management actions are implemented, because detectable changes in population structure may not occur until well into the future. Thus, realization of outcomes from management actions is a long-term proposition, which requires patience and a long-term commitment from resource agencies.

RIPRAP ACTIVITIES LINKED TO CONCEPTUAL MODELS

Overview of Recovery Action Plan

The Recovery Implementation Program Recovery Action Plan (RIPRAP) was developed by Recovery Program participants in 1996 in support of the basin-wide programmatic Section 7 agreement (U.S. Fish and Wildlife Service 2009, http://coloradoriverrecovery.org/ documents-publications/foundational-documents/recovery-action-plan.html) for the four endangered fishes. The RIPRAP identifies specific activities and time frames for carrying out those activities that contribute to recover the endangered fishes in the upper basin in the most expeditious manner. The RIPRAP is the Recovery Program's long range plan and contains dates for accomplishing specific activities over the next 5 years and beyond.

The RIPRAP provides guidance and serves as a measure of progress to determine how well the Recovery Program offsets depletion effects associated with projects undergoing Section 7 consultation. The RIPRAP annually updates activities for the Green, Yampa, Duchesne, White, Colorado, Gunnison, and Dolores rivers for each of the seven program elements. The RIPRAP is by its own purpose a dynamic document in which activities and resulting projects may be discontinued or revised. For this reason, we have provided the following section on general Recovery Program management actions to consolidate some of these projects into meaningful actions that can be appropriately evaluated.

General Recovery Program Management Actions

Recovery Program activities are structured under five major recovery elements: habitat management (instream flow identification and protection); habitat development (habitat restoration, including construction of fish passages and screens and restoration of floodplains); nonnative fish management; propagation and stocking; and research and population monitoring. Information gained from these activities forms the basis for making revisions and refinements to the RIPRAP under the principles of adaptive management. We identify the actions under each of these general recovery elements to better evaluate how RIPRAP activities are being implemented.

Instream Flow Protection

Identification and protection of instream flows are key elements in securing, protecting, and managing sufficient habitat to support self-sustaining populations of the endangered fishes. Flow recommendations are the first step in managing water in the upper basin in a manner that is consistent with species recovery and in compliance with all applicable laws and compacts. Flow recommendations have been developed for rivers in the upper basin, including the Upper Colorado, Gunnison, Yampa, White, Green, and Duchesne rivers (Table 7). The intent of these recommendations is to identify and allow the Recovery Program to implement those recommended flows for particular river reaches that are believed to provide the most benefit to the endangered fishes, given the hydrologic reality of annual precipitation and human uses. These flow recommendations are being evaluated and may be modified so that river flows provide the maximum benefit for the endangered species.

Table 7. River reaches with flow recommendations.

River	Reference
Upper Colorado	Osmundson and Kaeding 1991; Osmundson et al. 1995; McAda 2003
Gunnison	McAda 2003
Yampa	Tyus and Karp 1989; Modde and Smith 1995; Modde et al. 1999
Green	USFWS 1992; Muth et al. 2000
White	Irving et al. 2004
Duchesne	Modde and Keleher 2003

The Recovery Program uses a variety of mechanisms to provide and protect instream flows for the endangered fishes, including reoperation of Federal reservoirs, construction of additional water storage, improved irrigation efficiency, cooperative reservoir operations, contracts and leases, and instream flow filings.

Flows from Flaming Gorge on the Green River and the Aspinall Unit on the Gunnison River are being managed to benefit the endangered fishes by providing higher peaks in the spring and more appropriate base flows in the summer, fall, and winter, when practical. A recent research emphasis in the middle Green River is to understand the link between timing and magnitude of spring flow releases from Flaming Gorge Dam to inundate flood plain wetland habitat and timing of availability of razorback sucker larvae for entrainment into those flood plain wetlands (Studies 22F and FR-FP Synthesis). Flood plain wetlands are thought important areas for recruitment of razorback suckers but that process is further complicated by the presence of non-native fishes that compete with or prey upon early life stages of razorback sucker. The recruitment process for razorback suckers in flood plain wetlands, with interacting effects of stream flows, timing of fish reproduction, and negative effects of non-native fishes will continue to be an area of research emphasis for some time to come.

Green River flows in spring also transport sand and influence later-season sand bar elevations upon which backwaters form. Summer flows from Flaming Gorge Dam maintain those same backwaters in the middle and lower Green River. Backwaters provide habitat for age-0 Colorado pikeminnow and others fishes in the Green and Colorado rivers, including abundant non-native taxa. Recent reductions in abundance of age-0 Colorado pikeminnow, especially in the middle Green River, have prompted investigations into effects of flows on backwater formation, topography, and stability, and potential effects of non-native fishes (projects 138, FR-BW); those reductions were among several factors responsible for initiating this project. Recruitment processes for early life stages of Colorado pikeminnow are complicated and involve interactions between biotic and abiotic processes including flows, water temperature, and non-native fishes. A better understanding of those processes is needed for conservation activities to proceed and is a research need in the future.

Coordinated Reservoir Operations (CROS) is a program of voluntary operational coordination of selected reservoirs in the Upper Colorado River Basin upstream from the confluence of the Colorado and Gunnison rivers. The goal is to enhance spring peak flows to improve endangered fish habitat in the 15-Mile Reach of the Upper Colorado River without diminishing reservoir yields or affecting the timing of reservoir filling. The 15-Mile Reach is important habitat to many native fishes, and has been known to be used as a spawning area (along with the 18-mile reach) for the Colorado pikeminnow in the Upper Colorado River. Participating reservoirs in the past have included Green Mountain and Ruedi (Reclamation), Wolford Mountain (Colorado River Water Conservation District), Dillon and Williams Fork (Denver Water), and Willow Creek and Granby (Northern Colorado Water Conservancy District & Reclamation). CROS occurs in years when sufficiently high runoff conditions allow participating reservoirs to contribute without affecting their yield. The intent of CROS is to attempt to coordinate releases of inflow to enhance the natural peak flows on the Colorado for 10–14 days. This typically occurs during the last week of May and the first week of June.

Base flows on the Colorado River are enhanced through irrigation efficiency projects and releases from upstream reservoirs averaging 68,444 acre-feet per year since 1998. Yampa River base flows are enhanced through releases from Elkhead Reservoir. Duchesne River base flows are enhanced through a cooperative water management effort, helped by recent rehabilitation of the Myton Diversion Dam.

Habitat Restoration

Fish passage structures have been constructed on four mainstem diversion dams in the Upper Colorado River Basin to allow access by the four endangered fish species to over 180 km of additional historic habitat. These include nonselective fish passage completed in 1998 at the Grand Valley Irrigation Company Diversion, nonselective fish passage completed in 2008 at the Price-Stubb Diversion Dam, and selective fish passage completed in 2005 at the Grand Valley Project Diversion Dam (Table 8). These three dams are located on the Upper Colorado River just upstream of Grand Junction, Colorado, and the passage structures allow access to nearly 100 km of historic habitat to Rifle, Colorado. A selective fish passage structure was also completed in 1996 at the Redlands Water and Power Company Diversion on the lower Gunnison River; this passage allows access to over 80 km of historic habitat to Delta, Colorado. Populations of the Colorado pikeminnow and razorback sucker are expected to increase through expansion to these upstream reaches.

Table 8. Dams modified with fish passage (P) and associated canals with fish screening (S) to benefit the four endangered fish species of the Upper Colorado River Basin.

Structure	**85**	**86**	**87**	**88**	**89**	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**
Redlands Diversion Dam												P	P	P	P	P	P	P	P	P	P	P	P S	P S	P S
Grand Valley Irrigation Co. Diversion Dam														P	P	P	P	P S	P S	P S	P S	P S	P S	P S	P S
Grand Valley Project Diversion Dam																					P	P	P S	P S	P S
Price-Stubb Dam																								P	P

In addition to fish passage, fish screens were completed on the Grand Valley Irrigation Company Diversion Canal in 2002, on Grand Valley Project in 2007, and on the Redlands Water and Power Company Diversion Canal in 2005 to minimize entrainment of young native fishes. Additional fish passage for the Hartland Diversion Dam in the middle Gunnison River and fish screens on Tusher Diversion Canal in the middle Green River and the Maybell Ditch in the middle Yampa River are also being considered.

Operation and maintenance of these fish passage structures and screens should be supported to ensure that these continue to function properly and effectively. The fish passage structures provide valuable information on movement, growth, and survival of individuals captured in selective passages. Selective fish passages also allow for mechanical removal of problematic nonnative fishes. In systems like the Gunnison River, the Redlands fish passage is helping to regulate access by harmful nonnative fishes and much of the Gunnison River is dominated by a native fish community. These fish passages will also benefit the stocking program by increasing areas where hatchery fish can be stocked, without screens in place and passage built fish were not generally stocked above these structures in case of imprinting occurs or they might be susceptible to going into the irrigation canals.

Historically, Upper Colorado River Basin floodplains were frequently inundated by spring runoff, but today much of the river is channelized by levees, dikes, rip-rap, and tamarisk. Fish access to these flooded bottomlands has been further reduced by decreased peak spring flows due to upstream impoundments. Numerous studies have suggested the importance of seasonal flooding to river productivity, and floodplain habitats have been shown to contain large numbers of zooplankton and benthic organisms. Floodplain areas inundated and temporarily connected to the main channel by spring flows appear to be important habitats for all life stages of razorback sucker, and the seasonal timing of razorback sucker reproduction suggests an adaptation for utilizing these habitats. Floodplain habitats also may play an important role in bonytail life history. The Recovery Program developed floodplain management plans for both the Green and Colorado river subbasins (Valdez and Nelson 2004; Valdez and Nelson 2006) and manages approximately 2,700 acres of floodplain habitats along the Green (2,126 acres), Colorado (376 acres) and Gunnison (198 acres) rivers for the benefit of the endangered fishes. The importance of flood plain wetland habitat and stream flow timing and magnitude on razorback sucker recruitment is still under scrutiny and will continue to be a research emphasis for some time to come, especially in the middle Green River (synthesis project FR-FP). Further floodplain research on the Colorado and Gunnison rivers may be required to determine their benefit to the endangered fishes.

Nonnative Fish Management

Nonnative fish management is one of the most challenging elements of the Recovery Program. An important RIPRAP activity is the identification and implementation of viable active control measures to reduce the effect of problematic nonnative fishes. Mechanical removal has been identified as one of the most viable and practical activities in which individuals of a target species are removed from the system and either translocated to secure public fishing waters or euthanized. Nonnative fish have been removed opportunistically from the rivers during native species sampling since the Recovery Program's inception.

Concerted efforts to determine feasible approaches to nonnative species control, which have more recently evolved into research with a management application, have been in place for about 12 years (Table 9). Mark-recapture population estimates are done for each target species before removal begins so that the effect of removal can be quantified. A major effort is underway to summarize effects of removal of smallmouth bass from Upper Colorado River Basin streams (project 161 annual report). That effort will reformulate abundance estimates for reaches of the Colorado River, the middle Green River and Yampa River. Another component of that study is to formulate a smallmouth bass abundance dynamics model, using adult and early life smallmouth bass data, to evaluate and optimize a removal strategy for smallmouth bass in the system. Early life history data are a product of otolith analyses and capture data collected from several studies throughout the basin (projects 15, 115, 140, C18-19).

An offshoot of otolith analyses with young smallmouth bass is ongoing investigations to understand environmental factors including flow and water temperature relative to initiation and duration of the smallmouth bass spawning season. This information will increase the understanding of smallmouth bass ecology in both the Yampa and Green rivers (projects 115 and 140). That information may also be useful to understand when timed disturbances, such as higher or colder releases from Flaming Gorge Dam, may be most useful to hinder reproductive success of smallmouth bass in the Green River downstream of Flaming Gorge Dam.

Four nonnative fish species have been identified as particularly problematic and have been targeted for removal in various parts of the upper basin; northern pike, smallmouth bass, channel catfish, and white sucker. Other centrarchids (e.g., green sunfish, bluegill, crappie, and largemouth bass) are being removed from large backwaters in the Upper Colorado River and pilot studies have also been conducted to remove small-bodied fishes (e.g., red shiners, fathead minnow) from backwaters.

The benefits of mechanical removal vary throughout the Upper Basin and from year to year. Densities of adult smallmouth bass (>200mm TL) in the areas of highest concentration on the Yampa River were down in 2009, but were still greater than the Recovery Program's interim target of 30 fish /mile. Densities of adult northern pike (>300mm TL) in the upper Yampa River were approximately 10/mile in 2009; the interim target for that species is 3/mile. However, in the Yampa River where removal efforts have been most intensive, frequency and abundance of native fishes in main channel habitat has increased since 2005, and particularly in 2008 and 2009. Increased abundance of native fishes was thought a product of both non-native fish removal as well as increased spring and summer flow levels, which may suppress timing and success of smallmouth bass reproduction (Bestgen et al 2007, project 140 annual reports). Other positive changes have been reductions in the largest size classes of northern pike in the Yampa River, continued low abundance of northern pike in the middle Green River, and reductions in reproductive success of smallmouth bass in the middle Green River in 2008 and 2009. Those reductions may be a product of both removal efforts as well as higher and cooler flow conditions which limit reproductive success of smallmouth bass.

A summary of the history and current status of the Recovery Program's progress to reduce abundance of nonnative fishes over the last decade was taken from the 2008–2009 Annual

Table 9. A history of nonnative fish removal in the Upper Colorado River Basin.

Nonnative Fish and River Reach	**85**	**86**	**87**	**88**	**89**	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**
Northern Pike																									
Green River																					X	X	X	X	X
Yampa River															X	X	X	X	X	X	X	X	X	X	X
Smallmouth Bass																									
Yampa River																				X	X	X	X	X	X
Middle Green River																					X	X	X	X	X
Desolation/Gray Canyon																					X	X			
Upper Colorado River																						X	X	X	X
Channel Catfish																									
Desolation/ Gray Canyon													X	X											
Uintah Basin													X	X	X										
Yampa Canyon														X	X		X	X	X	X	X	X			
White Sucker																									
Middle Green Yampa River																							X	X	X
Others																									
Small-bodied fish in Colorado and Green River backwaters													X	X	X	X	X								
Centrarchids in Upper Colorado River backwaters															X	X	X			X	X	X	X	X	X
Stable isotopes / otolith microchemistry to determine sources of NNF																				X	X	X	X	X	X

Program Highlights (Table 10). Removal has been effective at reducing numbers of northern pike, but the source needs to be controlled. Removal of smallmouth bass has had variable results with substantial reductions in certain concentration areas. Other projects are designed to determine the native fish response to nonnative fish removal (projects 140 and 158).

The Recovery Program has developed standardized data collection formats which are compiled in a specific nonnative fish database. That database will be integral to CSU's evaluation of the Recovery Program's current approach to nonnative fish management as well as similar data syntheses in the future.

Since 2004, the Recovery Program has been experimenting with state of the art techniques to determine the provenance of nonnative fish found in the rivers – otolith microchemistry.

Table 10. The history and current status of the Recovery Programs' progress to reduce abundance of nonnative fishes over the past 10 years.

River (removal area)	Species	History and Current Status
Colorado (112 miles)	Smallmouth Bass	• Increases in abundance first observed in 2003; removal began in 2004. • Abundance declined during 2006-2008; removal passes added in 2007 to increase captures. • Largemouth bass are emerging problem; catch of young increased since 2004.
Green (198 miles)	Smallmouth Bass	• Increases in abundance first observed in 2003; removal began in 2004. • Adult abundance declined over 50% in much of Green River, 2004-2006. • Increased efforts in 2007-2008 removed up to 90% of estimated adult population in certain high concentration areas.
	Northern Pike	• Since removal began in 2001, abundance has decreased by over 90%.
Yampa (94 miles)	Smallmouth Bass	• Increases in abundance first observed in 2000; removal began in 2004. • Results through 2007 indicated adult population declining; but, substantial reproduction occurred in 2006-2007. • Average 2008 flows in Yampa, Green, and Colorado rivers appear to have negatively affected reproduction.
	Northern Pike	• Abundance steadily increased in 1980s and 1990s; removal began 1999. • Removal through 2007 shifted size to smaller individuals; in 2008, overall abundance in critical habitat was near its lowest level.

This work first targeted centrarchids in the Grand Valley of Colorado, but has more recently expanded to look at a variety of species throughout the Upper Basin.

In addition to the mechanical removal efforts the Recovery Program and its partners utilize passive control techniques such as screens on the outlet at Elkhead Reservoir in the Yampa river system; at the inflow to Rio Blanco Lake in the White River system; and a net to prevent escapement of nonnatives from Highline Lake located at the terminus of the Grand Valley Canal. All nonnative species are removed when encountered at selective fish passage structures at the Redlands Diversion and Grand Valley fish ladders.

The Recovery Program and its partners have also addressed nonnative fish management on the programmatic level. In 1996 the Service and the Upper Basin States instituted Nonnative Stocking Procedures to greatly reduce potential threats associated with State and Federal nonnative sportfish management. Those Procedures were updated and extended in 2009. In 2004, in response to a directive from the Recovery Program's Implementation Committee, the Recovery Program formalized its commitment to sound science and adaptive management with regard to nonnative fish management via a Nonnative Fish Management Policy. More specifically, in 2008 the Recovery Program built on that Policy and developed a Yampa River Nonnative Fish Control Strategy, which provides direct guidance via the Recovery Action Plan. The States of Colorado and Utah have eliminated possession and bag limits for nonnative species caught in the rivers. In 2008, the state of Utah implemented a

'must kill' policy for smallmouth bass caught in the Green River. The same applies to burbot (*Lota lota*) known to occur in Flaming Gorge Reservoir and Green River.
Also from the programmatic perspective are the Recovery Program's annual non-native fish workshops. These meetings are held in December of each year and began in 2003. At the workshops principal investigators present and discuss results of the past sampling seasons and to understand successes of the program. Biologists also develop and share ideas about new equipment or strategies to better accomplish removal. One such strategy being implemented in spring 2010 is concentrated effort targeting removal of spawning smallmouth bass in reaches of the Yampa River by several crews.

Research and Monitoring

The importance of quantifying numbers of endangered fishes in the upper basin was recognized before the Recovery Program was formed in 1988. In 1986, federal and state agencies formed the Interagency Standardized Monitoring Program (ISMP) as a cooperative and interactive effort to quantify numbers for various life stages of the four species (Tables 11 and 12 in part). Initial abundance estimates were catch-per-unit-effort (CPUE) indices including numbers of age-0 Colorado pikeminnow per area seined in backwaters, numbers of subadult and adult Colorado pikeminnow captured per unit time electrofishing, or numbers of subadult and adult humpback chub per hour of trammel net sampling.

Catch rate estimates were useful as indices of the general magnitude of population size and as a characterization of long-term trends. Robust data analyses using long-term data sets for razorback sucker included understanding reproductive success of wild and stocked fish in the Green River, which extended from 1992-present (Muth et al. 1998, Bestgen et al. 2002, Bestgen and Haines 2010, ongoing sampling under project 22f), and adult life stage abundance, survival, and population rate of change estimation using data collected beginning in 1979 through 2008 (Lanigan and Tyus 1989, Modde et al. 1996, Bestgen et al. 2002, Zelasko et al. 2009). Examples of long-term data sets used to understand abundance trends for Colorado pikeminnow include drift net sampling for larvae in the Colorado and Green rivers which began as early as 1983 (Nesler et al. 1988, Anderson 1998, Bestgen et al. 1998, ongoing study FR-BW synthesis, ongoing results from project 22f), age-0 seine sampling data used to show recruitment patterns from1986-2010 (Muth et al. 2000, Bestgen et al. 2007; Osmundson and White 2009, Bestgen et al. 2010, Breen et al 2010, ongoing project 138 and FR-BW synthesis), and adult Colorado pikeminnow recapture data collected since 1991 that has been used to estimate survival, recruitment, and population rates of changes in the Colorado and Green rivers (Osmundson and Burnham 1998; Bestgen et al. 2007, Osmundson and White 2009, Bestgen et al. 2010).

Long-term trends in humpback chub abundance based on trammel net sampling have also been made in most reaches that support the species (Chart and Lentsch 1999, McAda 2002, Hudson and Jackson 2003, Jackson and Hudson 2005, Finney 2006, Badame 2008, Badame 2009, Francis 2010, others). Long-term abundance dynamics for early life stages have been limited because accurate differentiation of humpback chub from other chubs, especially roundtail chub is difficult. Research and monitoring activities for bonytail have been limited

Table 11. A history of trend and abundance estimation sampling by year (1985–2009) for the Colorado pikeminnow and humpback chub in the Upper Colorado River Basin. Many early life stage and adult sampling and estimation programs are ongoing for 2010 and beyond.

Reaches	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10
Colorado pikeminnow																										
Colorado River																										
Larval drift								X	X	X	X	X														
ISMP-YOY		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
ISMP-S&A		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X										
Pop. Est.								P	P	P				P	P	P			P	P	P			P	P	P
Lower Green River																										
ISMP-YOY		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
ISMP-S&A		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X										
Pop. Est.																	P	P	P			P	P	P		
Desolation/Gray Canyon																										
Larval drift							X	X	X	X	X	X		X	X											
ISMP-S&A												X		X												
Pop. Est.																	P	P	P			P	P	P		
Middle Green River																										
Larval drift						X				X	X														X	X
ISMP-YOY		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
ISMP-S&A		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X										
FR-BW synth.																									X	X
Pop. Est.																P	P	P	P			P	P	P		
Yampa River																										
Larval drift	X	X	X	X		X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
ISMP-S&A		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X										
Pop. Est.																P	P	P	P			P	P	P		
White River																										
ISMP-S&A		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X										
Pop. Est.																P	P	P	P			P	P	P		
Humpback chub																										
Black Rocks																										
ISMP-TN				X			X																			
Pop. Est.														P	P	P			P	P			P	P		?
Westwater Canyon																										
ISMP-TN		X	X	X	X	X	X	X	X	X	X	X														
Pop. Est.														P	P	P			P	P	P		P	P		
Desolation/Gray Canyons																										
ISMP-TN	X	X	X	X	X	X	X	X	X	X	X	X														
Pop. Est.																	P	P	P			P	P		C	
Yampa River																										
ISMP-EL&AN			X	X	X																					
Pop. Est.																P	P	P	P				C			?
Cataract Canyon																										
BW/BOR	X	X	X	X																						
BW/UDWR					X	X	X	X																		
UDWR												X		X	X										X	X
Pop. Est.																			P	P	P					

ISMP-YOY= Interagency Standardized Monitoring Program-Age-0 monitoring with beach seines (1986-2000), or predecessors of that such as ongoing Recovery Program Project 138 conducted by Utah Division of Wildlife Resources.
ISMP-S&A= Interagency Standardized Monitoring Program-Subadult and adult monitoring with electrofishing
ISMP-TN=Interagency Standardized Monitoring Program-Trammel net
ISMP-EL&AN= Interagency Standardized Monitoring Program-Electrofishing and angling
Larval drift = Recovery Program project 22f and precursors conducted by the Larval Fish Laboratory from 1990-2009 (except 1997) in the Yampa River and the Green River in Desolation-Gray Canyon and the middle Green River (Bestgen et al. 1998), plus sampling by Colorado Division of Wildlife in the Yampa (T. Nesler) and Colorado (R. Anderson) rivers.
BW synthesis study (FR-BW synthesis, project 158)
BW/BOR=Bio/West/Bureau of Reclamation; BW/UDWR=Bio/West/Utah Division of Wildlife Resources
UDWR=Utah Division of Wildlife Resources
Pop. Est.=Mark-recapture population estimate (P)
X=relative abundance estimate as CPUE
C = captive population sampling
? = collection of fish for captivity

Table 12. A history of relative and absolute abundance estimates by year (1985–2009) for razorback sucker of various life stages in the Upper Colorado River Basin.

Reaches	**85**	**86**	**87**	**88**	**89**	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**
Upper Colorado River																										
ISMP-YOY		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X										
Larvae, LT																		X	X	X	X	X	X			
ISMP-S&A		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X										
Demo/Pop Est.							X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Lower Green River																										
ISMP-YOY									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Larvae, LT									X	X	X	X	X	X	X									X	X	X
ISMP-S&A		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X										
Demo/Pop Est.												X	X	X	X	X	X	X	X	X	X	X	X	X		
Desolation/Gray Canyon																										
Pop. Est.																	A	A	A			A	A	A		
Middle Green River																										
ISMP-YOY		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Larvae, LT								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
ISMP-S&A		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X										
Demo/Pop Est.	A	A	A	A	A	A	A	A	A	A	A	B	B	B	B	X	X	X	X	X	X	X	X	X		
Yampa River																										
ISMP-S&A		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X										
Larval drift	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
Pop. Est.																A	A	A	A			A	A	A		
White River																										
ISMP-S&A		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X										
Pop. Est.																A	A	A	A			A	A	A		

ISMP YOY = backwater seine sampling in autumn, mostly designed for Colorado pikeminnow.
Larvae, LT = light trap sampling: Colorado River (Osmundson and Seal 2009, project 121); middle and lower Green River (Muth et al. (1998), Bestgen et al. (2002), and Bestgen and Haines 2010 (FR-FP Synth.)); ongoing project 22f and its precursors.
ISMP-S&A = main channel boat electrofishing sampling, targeted sub-adult and adult Colorado pikeminnow, also collected large numbers of razorback sucker. Replaced by mark/recap population estimation.

Demo/Pop Est = abundance estimates based on analysis of tagged and recaptured razorback sucker and reported by Lanigan and Tyus (1989), Modde et al. (1996) and Bestgen et al. (2002, in part Basinwide Monitoring Program, Recovery Program project 22D) which were denoted "A", demographic analyses of Zelasko et al. (2009, Recovery Program Project 128) and Zelasko et al. (Recovery Program Project 128, in part) denoted as "X", or both, which were denoted by "B", or data on razorback sucker recaptures gathered under different abundance estimation sampling programs (Pop. Est.) such as Bestgen et al. 2007, Bestgen et al. 2010, and Osmundson and Seal 2009, denoted (A), which did not fit under any of the other categories.

to occasional monitoring of stocked populations and include efforts by Badame and Hudson (2001) and Bestgen et al. (2008).

The first capture-recapture studies using tagged fish in the Upper Colorado River Basin were conducted for razorback sucker in the middle Green River (Lanigan and Tyus 1989, Modde et al. 1996). Use of Passive Integrated Transponder (PIT) tags in the upper basin beginning in 1991 made it possible to implement more reliable mark-recapture population abundance estimators and survival models. The first mark-recapture population estimates in the upper basin using PIT tags were in 1991 for Colorado pikeminnow of the Upper Colorado River subbasin. Since that time, sampling for Colorado pikeminnow abundance estimation has occurred on an approximately 3 years on, 2 years off schedule and humpback chub abundance estimation has occurred on an initial 3 years on, 2 years off schedule then 2-on, 2-off, to achieve a balance between obtaining adequate data, while minimizing stress to the fish from sampling. Abundance estimates are a reliable method to monitor these populations, and researchers should strive to improve and refine methodologies to improve their accuracy and precision. It is evident from tables 7 and 8 that most mark-recapture population estimates have been done in the last decade and most populations of Colorado pikeminnow and humpback chub have only one or two 3-year rounds of estimates so trends for those species with long generation times are just beginning to emerge.

Propagation and Genetics

Numbers of razorback sucker and bonytail in the upper basin declined through the latter half of the 20th century and the Recovery Program is trying to reverse this trend with habitat improvement, flow management, and hatchery augmentation of wild stocks. Since implementation of the 2003 stocking plans (2004–2009), about 175,000 subadult razorback sucker, 95,000 subadult bonytail, and over 5,000 subadult Colorado pikeminnow have been stocked in the upper basin. Annual target for razorback sucker each in the Colorado and Gunnison, middle Green, and lower Green rivers is 9,930; average number stocked per river reach was 9,720 (Table 13). The annual target for bonytail each in the Colorado, middle Green and lower Green rivers is 5,330 fish; average stocked per river reach was 5,274.

Table 13. Annual target numbers of razorback sucker and bonytail to be stocked in the Upper Colorado River Basin and actual numbers of fish stocked since 2004.

River	Annual Target	Fish Stocked 2004	2005	2006	2007	2008	2009
Razorback sucker							
Colorado and Gunnison	9,930	6,258	11,633	11,559	10,098	12,949	12,949
Middle Green	9,930	10,126	4,878	10,091	11,014	11,677	11,677
Lower Green	9,930	3,445	4,243	10,313	8,539	10,161	10,161
Bonytail							
Colorado and Gunnison	5,330	8,219	6,067	5,554	5,570	5,896	5,085
Middle Green	5,330	3,500	5,980	5,045	5,409	7,641	5,403
Lower Green	5,330	3,100	3,100	3,270	5,404	5,336	5,347

RIPRAP Activities Linked to Species Life Histories

The biotic and abiotic controlling factors each life stage of the four endangered fishes are presented in Tables 14–17 along with associated principal RIPRAP activities, information gaps, and research recommendations. Only the principal RIPRAP activities are identified, although the more detailed subactivities that are found in the annual RIPRAP were considered when information gaps and research recommendations were identified. Some information gaps are identified without research recommendations because the particular gap may be difficult to address with a reasonable amount of effort and corrective actions may be very difficult with outcomes that have a high degree of uncertainty. Recommendations for new research are highlighted with bold letters on a gray background in Tables 14–17. These recommendations are fully discussed and listed in the following section on information needs and recommendations.

Only those research needs that we felt were not being addressed by the Recovery Program are identified as recommendations for new research. Although there remain a number of information gaps regarding the four endangered fish species, ongoing projects are addressing these and making progress. We encourage the Recovery Program to continue the current monitoring and research efforts, particularly those that are long-standing, and find no major projects that we believe should be discontinued.

It should be noted that the RIPRAP is a dynamic document that changes every year according to findings of previous work. Matching every controlling factor of every life stage of each species is unwieldy and impractical. Not only might activities change in the RIPRAP from one year to the next but in some cases, a particular controlling factor may have been addressed in prior years and no long appears as an activity in the RIPRAP. For these cases, we used past reports and publications as well as our knowledge of prior work in the upper basin.

Table 14. Biotic and abiotic controlling factors by life stage of Colorado pikeminnow (CPM) and associated principal RIPRAP activities, information gaps, and recommendations for new research. Adopted from General Recovery Program Support Action Plan. Recommendations for ongoing and new research are identified in bold with a gray background.

Development Stage	Biotic and Abiotic Controlling Factors	Principal RIPRAP Activity	Information Gap	Recommendations for Ongoing and New Research
Embryos and larvae in substrate	Biotic: Adult numbers, condition, size, age; embryo survival, predation; timing of spawning; physical disturbance of spawning sites	• III.A. Reduce negative interactions between nonnative and endangered fishes. • III.B. Reduce negative impacts to endangered fishes from sportfish management activities. • V.A. Measure and document populations. • V.B. Conduct research to acquire needed life history information.	• Predation on embryos and larvae unknown. • Physical disturbance of spawning sites unknown.	• Difficult to quantify and target predators on spawning bars. • Difficult to quantify and target disturbances on spawning bars.
	Abiotic: Runoff timing, magnitude; substrate (sediment deposition, siltation, oxygen); flow fluctuations; temperature; stochastic events	• I.A. Evaluate methods for defining habitat-flow needs. • I.B. Develop and select methods for modifiable protection of instream flows in Colorado. • I.C. Develop an enforcement agreement between the Service and appropriate State agencies to protect instream flows.	• Exact combination of conditions for spawning, embryos, and larvae not fully quantified, but sufficiently understood.	• Spawning studies in the Upper Colorado River should focus on identifying suitable spawning habitats and determining the effects of peak flow, base flow, and sediment characteristics on spawning habitat.
Dispersing larvae in main channel and channel margins	Biotic: Predation; starvation; habitat selection	• III.A. Reduce negative interactions between nonnative and endangered fishes. • III.B. Reduce negative impacts to endangered fishes from sportfish management activities. • V.B. Conduct research to acquire needed life history information.	• Predation on drifting larvae unknown. • Starvation by drifting larvae unknown.	• Difficult to quantify and target predators feeding on drift. • Difficult to quantify starvation of drifting larvae.
	Abiotic: Spring runoff magnitude, duration; water temperature; geomorphic factors; turbidity	• I.A. Evaluate methods for defining habitat-flow needs. • I.B. Develop and select methods for modifiable protection of instream flows in Colorado. • I.C. Develop an enforcement agreement between the Service and appropriate State agencies to protect instream flows.	• Exact combination of conditions for spawning not fully quantified, but sufficiently understood.	• Considerable work has been done on quantifying flows to maximize backwater habitats.
Age-0 in nursery habitat	Biotic: Predation; growth rate; condition/starvation;	• III.A. Reduce negative interactions between nonnative and endangered fishes. • III.B. Reduce negative impacts to endangered fishes from sportfish	• Effects of predation and competition on age-0 CPM in nursery	**1. Identify and address sources of mortality (e.g., predation and**

Development Stage	Biotic and Abiotic Controlling Factors	Principal RIPRAP Activity	Information Gap	Recommendations for Ongoing and New Research
	food; competition	management activities. • V.B. Conduct research to acquire needed life history information.	backwaters not well understood. Interactions between flows, habitat, sand bar and backwater topography and availability, and effects on age-0 Colorado pikeminnow and non-native fishes not well understood.	**competition) for age-0 CPM in nursery backwaters. The current approach is two-tailed: 1) develop an effective nonnative fish management program, and 2) develop specific efforts to control nonnative species abundance to temporally benefit native species in backwaters. Other ongoing studies also address this, in part (projects 22f, 138, FR-BW synthesis, backwater studies)**
	<u>Abiotic</u>: Discharge and geomorphic related habitat; discharge fluctuations, habitat stability; water temperature; stochastic events	• I.A. Evaluate methods for defining habitat-flow needs. • I.B. Develop and select methods for modifiable protection of instream flows in Colorado. • I.C. Develop an enforcement agreement between the Service and appropriate State agencies to protect instream flows.	• Summer and fall flows have not been evaluated to ensure suitable backwater formation. See just above on interactions between flows, habitat and non-native fishes and effects on young pikeminnow.	**2. Determine most suitable summer and fall flows for age-0 CPM nursery backwater formation. A synthesis of how environmental conditions influence the backwaters and backwater fish communities was initiated in 2009, which is intended to address this uncertainty. Other studies are ongoing (e.g., 22f, 138) which provide the background data for syntheses.**

Development Stage	Biotic and Abiotic Controlling Factors	Principal RIPRAP Activity	Information Gap	Recommendations for Ongoing and New Research
Age-0, age-1 in winter habitat	Biotic: Predation, energy stores; swimming ability; food; movement	• III.A. Reduce negative interactions between nonnative and endangered fishes. • III.B. Reduce negative impacts to endangered fishes from sportfish management activities. • V.B. Conduct research to acquire needed life history information.	• Effects of predation and competition on age-0, age-1 CPM in winter related to size of fish entering winter,	**3. Identify and address sources of mortality (e.g., predation and competition) for age-0, age-1 CPM in winter. Aspects of overwinter survival have already been investigated (Haines et al. 1998)**
	Abiotic: Discharge related habitat; discharge fluctuations, habitat stability; water temperature	• I.A. Evaluate methods for defining habitat-flow needs. • I.B. Develop and select methods for modifiable protection of instream flows in Colorado. • I.C. Develop an enforcement agreement between the Service and appropriate State agencies to protect instream flows.	• Relationships of winter flows to backwater habitat suitability have been studied.	• Relationships of winter flows to backwater habitat suitability have been studied.
Juvenile and adult	Biotic: Predation; food; competition; movement; reproduction; diseases and parasites	• III.A. Reduce negative interactions between nonnative and endangered fishes. • III.B. Reduce negative impacts to endangered fishes from sportfish management activities. • V.A. Measure and document populations. • V.B. Conduct research to acquire needed life history information. • V.H. Reevaluate effects of disease and parasites.	• Effects of predation and removal of target nonnative fish species not well understood.	**4. Implement innovative techniques for evaluating effectiveness of nonnative fish management on the endangered fishes. The first step is a comprehensive evaluation of the current approach, which was initiated in 2009. Evaluation is also conducted via estimating population abundances of endangered fishes on a regular basis and in projects 138 and 140.**
	Abiotic: Floodplain connectivity; discharge related	• I.A. Evaluate methods for defining habitat-flow needs. • I.B. Develop and select methods for modifiable protection of instream flows in Colorado.	• Effects of drought not well understood.	**5. Implement climate change initiative that outlines strategy for**

Development Stage	Biotic and Abiotic Controlling Factors	Principal RIPRAP Activity	Information Gap	Recommendations for Ongoing and New Research
	habitat; water temperature; stochastic events (pollutants); drought; blocked passage; entrainment	• I.C. Develop an enforcement agreement between the Service and appropriate State agencies to protect instream flows. • II.A. Restore flooded bottomland habitats. • II.C. Develop an issue paper on the desirability and practicality of restoring and protecting certain portions of the floodplain		**dealing with drought, reduced stream flow, and associated effects.** **6. Continue to support efforts of other agencies to evaluate the effects of water pollutants**

Table 15. Biotic and abiotic controlling factors by life stage of humpback chub (HBC) and associated principal RIPRAP activities, information gaps, and recommendations for ongoing and new research. Adopted from General Recovery Program Support Action Plan. Recommendations for new research are identified in bold with a gray background.

Development Stage	Biotic and Abiotic Controlling Factors	Principal RIPRAP Activity	Information Gap	Recommendations for Ongoing and New Research
Embryos and larvae in substrate	Biotic: Adult numbers, condition, size, age; embryo survival, predation	• III.A. Reduce negative interactions between nonnative and endangered fishes. • III.B. Reduce negative impacts to endangered fishes from sportfish management activities. • V.A. Measure and document populations. • V.B. Conduct research to acquire needed life history information.	• Predation on embryos and larvae unknown. • Survival of embryos and larvae unknown.	• Difficult to quantify and target predators of embryos and larvae. • Difficult to quantify survival of embryos and larvae.
	Abiotic: Runoff timing, magnitude; substrate (sediment deposition, siltation, oxygen); flow fluctuations; temperature; stochastic events	• I.A. Evaluate methods for defining habitat-flow needs. • I.B. Develop and select methods for modifiable protection of instream flows in Colorado. • I.C. Develop an enforcement agreement between the Service and appropriate State agencies to protect instream flows.	• Exact combination of conditions for spawning, embryos, and larvae not fully quantified, but not critical.	• Difficult to quantify flow timing, magnitude, fluctuations, etc. for spawning, embryos, and larvae in spawning sites.
Dispersing larvae in main channel and channel margins	Biotic: Predation; starvation; habitat selection	• III.A. Reduce negative interactions between nonnative and endangered fishes. • III.B. Reduce negative impacts to endangered fishes from sportfish management activities. • V.B. Conduct research to acquire needed life history information.	• Predation on larvae unknown. • Starvation by larvae unknown.	• Difficult to quantify and target predators feeding on larvae • Difficult to quantify starvation of larvae.
	Abiotic: Spring runoff magnitude, duration; water temperature; geomorphic factors; turbidity	• I.A. Evaluate methods for defining habitat-flow needs. • I.B. Develop and select methods for modifiable protection of instream flows in Colorado. • I.C. Develop an enforcement agreement between the Service and appropriate State agencies to protect instream flows.	• Exact combination of conditions for spawning not fully quantified, but sufficiently understood.	• None.
Age-0 in nursery habitat	Biotic: Predation; growth rate; condition/starvation; food; competition	• III.A. Reduce negative interactions between nonnative and endangered fishes. • III.B. Reduce negative impacts to endangered fishes from sportfish management activities. • V.B. Conduct research to acquire needed life history information.	• Effects of predation and competition on age-0 HBC in nursery habitats not well understood.	**7. Identify and address sources of mortality (e.g., predation and competition) for age-0 HBC in nursery habitats. The Program**

Development Stage	Biotic and Abiotic Controlling Factors	Principal RIPRAP Activity	Information Gap	Recommendations for Ongoing and New Research
				currently monitors abundance of YOY chubs in some reaches in response to non-native fish removal and other management activities (projects 115, 140)See comment above with regard to Age0 CPM. Specific studies to characterize this threat in HBC nursery habitats is not currently scheduled.
	Abiotic: Discharge and geomorphic related habitat; discharge fluctuations, habitat stability; water temperature; stochastic events	• I.A. Evaluate methods for defining habitat-flow needs. • I.B. Develop and select methods for modifiable protection of instream flows in Colorado. • I.C. Develop an enforcement agreement between the Service and appropriate State agencies to protect instream flows.	• Summer and fall flows have not been evaluated to ensure suitable habitat but not considered critical need.	• None.
Age-1 in rearing habitat	Biotic: Predation, energy stores; swimming ability; food; movement	• III.A. Reduce negative interactions between nonnative and endangered fishes. • III.B. Reduce negative impacts to endangered fishes from sportfish management activities. • V.B. Conduct research to acquire needed life history information.	• Effects of predation and competition on age-1 HBC in winter not well understood.	**8. Identify and address sources of mortality (e.g., predation and competition) for age-1 HBC in rearing habitat. The current approach is to implement an effective nonnative fish management program which targets what researchers believe are the most harmful nonnative species. The Program is monitoring abundance of young**

Development Stage	Biotic and Abiotic Controlling Factors	Principal RIPRAP Activity	Information Gap	Recommendations for Ongoing and New Research
				chubs in some reaches to determine response to r management activities (projects 115, 140)
	Abiotic: Discharge related habitat; discharge fluctuations, habitat stability; water temperature	• I.A. Evaluate methods for defining habitat-flow needs. • I.B. Develop and select methods for modifiable protection of instream flows in Colorado. • I.C. Develop an enforcement agreement between the Service and appropriate State agencies to protect instream flows.	• Relationships of winter flows to habitat suitability have not been studied, but not considered critical need.	• None.
Juvenile and adult	Biotic: Predation; food; competition; movement; reproduction; hybridization; diseases and parasites	• III.A. Reduce negative interactions between nonnative and endangered fishes. • III.B. Reduce negative impacts to endangered fishes from sportfish management activities. • V.A. Measure and document populations. • V.B. Conduct research to acquire needed life history information. • V.H. Reevaluate effects of disease and parasites.	• Effects of predation and removal of target nonnative fish species not well understood. • Lowered levels of Lake Powell may have allowed expansion of the Cataract population.	• **See #4 above.** **9. Investigate the Lake Powell inflow to determine if the Cataract population is expanding downstream.**
	Abiotic: Discharge related habitat; water temperature; stochastic events (pollutants); drought	• I.A. Evaluate methods for defining habitat-flow needs. • I.B. Develop and select methods for modifiable protection of instream flows in Colorado. • I.C. Develop an enforcement agreement between the Service and appropriate State agencies to protect instream flows.	• Effects of drought not well understood.	• **See #5 above.** • **See #6 above.**

Table 16. Biotic and abiotic controlling factors by life stage of razorback sucker (RBS) and associated principal RIPRAP activities, information gaps, and recommendations for ongoing and new research. Adopted from General Recovery Program Support Action Plan. Recommendations for new research are identified in bold with a gray background.

Development Stage	Biotic and Abiotic Controlling Factors	Principal RIPRAP Activity	Information Gap	Recommendations for Ongoing and New Research
Embryos and larvae in substrate	Biotic: Adult numbers, condition, size, age; embryo survival, predation; timing of spawning; physical disturbance of spawning sites	• III.A. Reduce negative interactions between nonnative and endangered fishes. • III.B. Reduce negative impacts to endangered fishes from sportfish management activities. • V.A. Measure and document populations. • V.B. Conduct research to acquire needed life history information.	• Adult numbers are unknown • Predation on embryos and larvae unknown. • Physical disturbance of spawning sites unknown.	• Develop population estimates for adult razorback sucker • Difficult to quantify and target predators on spawning bars. • Difficult to quantify and target disturbances on spawning bars.
	Abiotic: Runoff timing, magnitude; substrate (sediment deposition, siltation, oxygen); flow fluctuations; temperature; stochastic events	• I.A. Evaluate methods for defining habitat-flow needs. • I.B. Develop and select methods for modifiable protection of instream flows in Colorado. • I.C. Develop an enforcement agreement between the Service and appropriate State agencies to protect instream flows.	• Flow timing, magnitude, and duration for spawning, embryos, and larvae not known with certain, but probably driven more by floodplain connectivity.	• Spawning studies in the Upper Colorado River should focus on identifying suitable spawning habitats and determining the effects of peak flow, base flow, and sediment characteristics on spawning habitat • Follow up on new information and recommendations in synthesis FR-FP.
Dispersing larvae in main channel and channel margins	Biotic: Predation; starvation; habitat selection	• III.A. Reduce negative interactions between nonnative and endangered fishes. • III.B. Reduce negative impacts to endangered fishes from sportfish management activities. • V.B. Conduct research to acquire needed life history information.	• Predation on drifting larvae unknown. • Starvation by drifting larvae unknown.	• Difficult to quantify and target predators feeding on drift. • Laboratory work has been conducted on starvation of larvae.

Development Stage	Biotic and Abiotic Controlling Factors	Principal RIPRAP Activity	Information Gap	Recommendations for Ongoing and New Research
	Abiotic: Spring runoff magnitude, duration; water temperature; geomorphic factors; turbidity	• I.A. Evaluate methods for defining habitat-flow needs. • I.B. Develop and select methods for modifiable protection of instream flows in Colorado. • I.C. Develop an enforcement agreement between the Service and appropriate State agencies to protect instream flows.	• Flows to entrain drifting larvae not well understood but being studied.	• Follow up on new information and recommendations in synthesis FR-FP. Consider research to increase entrainment at downstream only breaches.
Larvae to juvenile in floodplain and main channel backwaters	Biotic: Predation; growth rate; condition/starvation; food; competition; tolerance of water quality; energy; swimming ability	• III.A. Reduce negative interactions between nonnative and endangered fishes. • III.B. Reduce negative impacts to endangered fishes from sportfish management activities. • V.B. Conduct research to acquire needed life history information.	• Effects of predation and competition on age-0 RBS in nursery floodplains being studied.	• None
	Abiotic: Magnitude and duration of peak flows for floodplains; discharge fluctuations and floodplains; water temperature; stochastic events; out year spring hydrology	• I.A. Evaluate methods for defining habitat-flow needs. • I.B. Develop and select methods for modifiable protection of instream flows in Colorado. • I.C. Develop an enforcement agreement between the Service and appropriate State agencies to protect instream flows.	• Flow magnitude and duration necessary to provide suitable floodplain connection for age-0 RBS being studied on Green River.	• Similar studies should be looked at on the Gunnisona and Colorado rivers.
Juvenile and adult	Biotic: Predation; food; competition; movement; reproduction; hybridization; diseases and parasites	• III.A. Reduce negative interactions between nonnative and endangered fishes. • III.B. Reduce negative impacts to endangered fishes from sportfish management activities. • V.A. Measure and document populations. • V.B. Conduct research to acquire needed life history information. • V.H. Reevaluate effects of disease and parasites.	• Effects of hybrization unknown. • Effects of predation and removal of target nonnative fish species not well understood.	• **See #4 above.** **10. Assess the extent of hybridization by white sucker on RBS.** **11. Assimilate and assess information on all stocked endangered fish that are recaptured.**
	Abiotic: Floodplain connectivity; discharge related habitat; water temperature; stochastic events (pollutants);	• I.A. Evaluate methods for defining habitat-flow needs. • I.B. Develop and select methods for modifiable protection of instream flows in Colorado. • I.C. Develop an enforcement agreement between the Service and appropriate State agencies to protect instream flows.	• None	• **See #5 above.** • **See #6 above.**

Development Stage	Biotic and Abiotic Controlling Factors	Principal RIPRAP Activity	Information Gap	Recommendations for Ongoing and New Research
	drought; blocked passage; entrainment	• II.A. Restore flooded bottomland habitats. • II.C. Develop an issue paper on the desirability and practicality of restoring and protecting certain portions of the floodplain		

Table 17. Biotic and abiotic controlling factors by life stage of bonytail (BT) and associated principal RIPRAP activities, information gaps, and recommendations for new research. Adopted from General Recovery Program Support Action Plan. Recommendations for new research are identified in bold with a gray background.

Developmental Stage	Biotic and Abiotic Controlling Factors	Principal RIPRAP Activity	Information Gap	Recommendations for New Research
Embryos and larvae in substrate	Biotic: Adult numbers, condition, size, age; embryo survival, predation; timing of spawning; physical disturbance of spawning sites	• III.A. Reduce negative interactions between nonnative and endangered fishes. • III.B. Reduce negative impacts to endangered fishes from sportfish management activities. • IV.E. Conduct monitoring to evaluate effectiveness and continuation of endangered fish stocking. • V.A. Measure and document populations. • V.B. Conduct research to acquire needed life history information.	• Predation on embryos and larvae unknown. • Physical disturbance of spawning sites unknown.	• Difficult to quantify and target predators on spawning bars. • Difficult to quantify and target disturbances on spawning bars.
	Abiotic: Runoff timing, magnitude; substrate (sediment deposition, siltation, oxygen); flow fluctuations; temperature; stochastic events	• I.A. Evaluate methods for defining habitat-flow needs. • I.B. Develop and select methods for modifiable protection of instream flows in Colorado. • I.C. Develop an enforcement agreement between the Service and appropriate State agencies to protect instream flows.	• Flow timing, magnitude, and duration for spawning, embryos, and larvae not known with certain, but probably driven more by floodplain connectivity.	• None.
Dispersing larvae in main channel and channel margins	Biotic: Predation; starvation; habitat selection	• III.A. Reduce negative interactions between nonnative and endangered fishes. • III.B. Reduce negative impacts to endangered fishes from sportfish management activities. • V.B. Conduct research to acquire needed life history information.	• Predation on drifting larvae unknown. • Starvation by drifting larvae unknown.	• Difficult to quantify and target predators feeding on drift. • Laboratory work has not been done on starvation of larvae.
	Abiotic: Spring runoff magnitude, duration; water temperature; geomorphic factors; turbidity	• I.A. Evaluate methods for defining habitat-flow needs. • I.B. Develop and select methods for modifiable protection of instream flows in Colorado. • I.C. Develop an enforcement agreement between the Service and appropriate State agencies to protect instream flows.	• Flows to entrain drifting larvae not well understood but being studied.	• None.

Developmental Stage	Biotic and Abiotic Controlling Factors	Principal RIPRAP Activity	Information Gap	Recommendations for New Research
Larvae to juvenile in floodplain and main channel backwaters	Biotic: Predation; growth rate; condition/starvation; food; competition; tolerance of water quality; energy; swimming ability	• III.A. Reduce negative interactions between nonnative and endangered fishes. • III.B. Reduce negative impacts to endangered fishes from sportfish management activities. • V.B. Conduct research to acquire needed life history information.	• Effects of predation and competition on age-0 BT in nursery floodplains continue to be studied.	• None.
	Abiotic: Magnitude and duration of peak flows for floodplains; discharge fluctuations and floodplains; water temperature; stochastic events; out year spring hydrology	• I.A. Evaluate methods for defining habitat-flow needs. • I.B. Develop and select methods for modifiable protection of instream flows in Colorado. • I.C. Develop an enforcement agreement between the Service and appropriate State agencies to protect instream flows.	• Flow magnitude and duration necessary to provide suitable floodplain connection for age-0 BT.	• None.
Juvenile and adult	Biotic: Predation; food; competition; movement; reproduction; diseases and parasites	• III.A. Reduce negative interactions between nonnative and endangered fishes. • III.B. Reduce negative impacts to endangered fishes from sportfish management activities. • IV.E. Conduct monitoring to evaluate effectiveness and continuation of endangered fish stocking. • V.A. Measure and document populations. • V.B. Conduct research to acquire needed life history information. • V.H. Reevaluate effects of disease and parasites.	• Effects of predation and removal of target nonnative fish species not well understood.	• **See #4 above.** • **See #11 above.** • Research can be conducted in areas of life history, habitat requirements and effects of predation once adult populations are re-established.
	Abiotic: Floodplain connectivity; discharge related habitat; water temperature; stochastic events (pollutants); drought; blocked passage; entrainment	• I.A. Evaluate methods for defining habitat-flow needs. • I.B. Develop and select methods for modifiable protection of instream flows in Colorado. • I.C. Develop an enforcement agreement between the Service and appropriate State agencies to protect instream flows. • II.A. Restore flooded bottomland habitats. • II.C. Develop an issue paper on the desirability and practicality of restoring and protecting certain portions of the floodplain	• None	• **See #5 above.** • **See #6 above.**

INFORMATION NEEDS AND RECOMMENDATIONS

Information Gaps and Needs

The following are information gaps and needs identified from linking RIPRAP activities with biotic and abiotic controlling factors for each of the four endangered fish species. Significant information needs and recommendations are bolded to highlight our findings in context of the discussion that links activities with controlling factors. Following the information needs is a list of recommendations for new research drawn from this discussion.

Colorado Pikeminnow

Of the five biotic controlling factors that affect the transition of Colorado pikeminnow from embryos and larvae in substrate to dispersing larvae in the main channel, the numbers and condition of adults and the age and size structure of the population are being addressed through the ongoing monitoring program of mark-recapture population estimates and their associated analyses. The researchers' ability to estimate timing of spawning has become quite refined from capture of drifting larvae, particularly from the lower Yampa River. This information has helped to coordinate releases from Flaming Gorge Dam with flows of the Yampa River to ensure suitable flows and water temperatures for larvae from the Yampa River entering the Green River. **Predation on embryos and larvae and physical disturbance of spawning sites by other fish are not being investigated. These controlling factors would be difficult to quantify and it could be difficult to target fishes on the spawning bars that may be contributing to these threats.** Nonnative fish are currently being removed from the Yampa River and the Green River near the known spawning bars, however densities of smallmouth bass (particularly juveniles) remain high. Considering current levels of removal effort as well as the pending programmatic evaluation of the Program's current approach we do not recommend additional studies at this time.

Three biotic controlling factors affect Colorado pikeminnow between the stage where larvae are dispersing in the main channel and the time the age-0 fish reach the nursery habitat. Habitat selection has been studied extensively and it is well understood that age-0 fish select primarily backwater habitats in alluvial sand-bed reaches. Selected backwaters generally have prescribed sizes, depths, and water quality characteristics as a result of a range in river flows. Researchers have not demonstrated a clear relationship between the amount of selected backwater habitats and age-0 pikeminnow cohort strength. In 2009, the Recovery Program contracted for the most comprehensive synthesis (project FR-BW Synth) to date of these related data (flow metrics, habitat measurements, pikeminnow collection data and backwater fish community information). The hope is that through this synthesis the Recovery Program will gain a better understanding of how spring and base flows during the first year of a pikeminnow life factor into age-0 abundance in the fall and ultimately recruitment. Predation and starvation of these early life stages have not been investigated in the wild, however these have been studied under laboratory conditions. **Predation and starvation of larvae have been quantified in the laboratory; and is not recognized as a primary threat.**

The biotic factors that affect age-0 Colorado pikeminnow in nursery habitat are possibly the most influential to survival and recruitment of the species. Monitoring of these fish in backwaters has been conducted annually since 1986. The monitoring program has documented annual densities of age-0 Colorado pikeminnow in these habitats and their growth rates. Ancillary studies of condition and starvation have also been done. But the interactions with other species that affect predation, food abundance, and intra- and interspecific competition in nursery backwaters have received less attention and are less understood. It is well known that nursery backwaters often have high densities of sympatric nonnative fishes that prey upon and compete with the age-0 Colorado pikeminnow. Laboratory studies show high attack rates by red shiners (*Cyprinella lutrensis*) and larvae hatched in midsummer or later have higher survival (Bestgen et al. 2006a). **We identify the lack of definitive information on sources of mortality (e.g., predation and competition) on age-0 Colorado pikeminnow in nursery backwaters as an information need. We recognize the recently initiated Recovery Program Project 158 as a first step to address this information need.** Food for young Colorado pikeminnow may be limiting in nursery habitats, particularly in light of information that suggests that late-hatched fish accumulate less fat storage and have lower over-winter survival. We believe the Recovery Program's current focus on predation and competition is the higher priority at this point in time.

Little is known about Colorado pikeminnow after they leave the nursery backwaters in spring of the year following their birth. There is some information on over-winter survival that indicates that fish in backwaters that are deep and persistent survive better than those in backwaters that are shallow or ephemeral. Colorado pikeminnow become piscivorous before their third month of life at which time there is an abundance of sympatric small-bodied fish in backwaters as food sources. However, the habitats used by the late age-0 and age-1 fish are not known with certainty and the factors that affect them at this life stage are poorly understood. **We identify the lack of definitive information on sources of mortality (e.g., predation and competition) on late age-0 and age-1 Colorado pikeminnow after they leave the nursery backwaters as an information need.**

Most studies of survival, growth, and recruitment of Colorado pikeminnow have involved the late juvenile and adult stages. This is primarily because these fish are easier to capture and mark for use with traditional mark-recapture estimation models. There is a considerable body of evidence from diet analyses, laboratory studies, community species composition, and individual observations that sympatric fish species, especially nonnative forms, impose a considerable toll on native species in the form of competition and predation. This evidence is sufficiently compelling to cause the Recovery Program to design and implement a large nonnative fish management element, including removal of the most problematic species, such as northern pike, smallmouth bass, and channel catfish. In 2009, the Recovery Program contracted with a team of researchers from Colorado State University to evaluate the current approach to smallmouth bass control. That team intends to expand the scope of recent population dynamics models using data collected in the system, the comprehensive non-native fish removal database, and their own unpublished information. Their goal is to develop a comprehensive age- or size-structured model to understand factors that affect smallmouth bass population dynamics in the Upper Colorado River Basin. Their model will include density-dependent feedback, and means to assess effects of environmental factors and management actions that can be manipulated independently of each other. The researchers also propose to address uncertainty and variability in the parameters and relationships in the model to address its influence on the outcomes and predictions. **We recommend continuation of this nonnative fish management element and promote this recently initiated effort to evaluate the current approach.**

The abiotic factors that affect Colorado pikeminnow are associated with river flow, water quality (e.g., temperature, pollutants), channel geomorphology, blocked passage, and entrainment in canals. Flow recommendations for the Green River, Yampa River, White River, Gunnison River, and Upper Colorado River prescribe those flows and temperatures needed by the four species for recovery. Agreements among water users and the Recovery Program provide for coordinated reservoir operations to meet target flows prescribed by these flow recommendations. The Recovery Program fully recognizes the need to evaluate the anticipated effects and uncertainties associated with our flow recommendations (e.g. the Green River Study Plan [Valdez et al. 2010] and the Aspinall Study Plan [indraft]). **However, the effects of water pollutants, especially selenium, mercury, and most recently pharmaceuticals, on the four endangered fish species are largely unknown. We recommend that the Recovery Program promote continued evaluation of these pollutants and the necessary remedial actions.** The threats of blocked passage and entrainment in canals are being addressed through construction of four fish passage structures and a fish screen on the largest canals in the upper basin. An overarching factor that may be having a large effect on fish populations in the upper basin is drought and more generally climate change. The effects of drought and climate change on the fishes of the upper basin are complex and the biotic and abiotic interactions cannot be easily assessed with a simple set of studies. **We recommend that the Recovery Program implement a climate change initiative that outlines a strategy for dealing with the effects of drought, reduced stream flow, and associated effects in the context of recovery of the four endangered fishes.**

Humpback Chub

Of the three biotic controlling factors that affect the transition of humpback chub from embryos and larvae in substrate to dispersing larvae in the main channel, the numbers and condition of adults and the age and size structure of the population are being addressed through the ongoing monitoring program of mark-recapture population estimates and their associated analyses. **Predation on embryos and larvae are not being investigated. These controlling factors would be difficult to quantify and it could be difficult to target fishes that may be contributing to these threats.** Nonnative fish are currently being removed from humpback chub population centers in Yampa Canyon and as needed from Desolation/Gray Canyon to reduce populations of potentially problematic species, and additional studies and/or management actions to attempt to address these controlling factors are not recommended.

Three biotic controlling factors affect humpback chub between the stage where larvae are dispersing in the main channel and the time the age-0 fish reach the nursery habitat. Little is known of humpback chub in their early life stage because these fish are found in remote canyon-bound areas at a time when river flows are near peak runoff. Habitat selection by these young fish has not been studied extensively, but most are found along shallow, sheltered channel margins in and near population centers. Also, the factors of predation and starvation have not been investigated. **Predation and starvation of larvae would be difficult to quantify and even more difficult to rectify, if a problem does in fact exist.**

The biotic factors that affect age-0 humpback chub in nursery habitats include predation, growth, condition and starvation, food abundance, and competition. Few age-0 and age-1 fish are handled by researchers and little is known of their fate and the factors that affect their survival, growth, and recruitment. Studies of habitat use in Grand Canyon revealed ontogenic shifts in habitat use from shallow shorelines to off-shore eddies and pools at about 1 to 2 years of age. **Because so little is known about the fate of young humpback chub, we recommend investigations into the fate of these fish until they become adults at about 200 mm TL or age-4.**
As with Colorado pikeminnow, most of the studies of survival, growth, and recruitment of humpback chub have involved the late juvenile and adult stages. This is primarily because these fish are easier to capture and mark for use of traditional mark-recapture survival, growth, and population estimation models. **As with Colorado pikeminnow, we recommend continued emphasis on nonnative fish management and expect the programmatic evaluation will inform the Recovery Program if more innovative techniques could be more successful or other populations centers, i.d., Black Rocks, Westwater, require similar efforts.**

The abiotic factors that affect humpback chub are associated with river flow, water quality (e.g., temperature, pollutants), and channel geomorphology. Flow recommendations for the Green River, Yampa River, White River, Gunnison River, and Upper Colorado River prescribe those flows and temperatures needed by the four species for recovery.

Agreements among water users and the Recovery Program provide for coordinated reservoir operations to meet target flows prescribed by these flow recommendations. Water pollutants, especially selenium, mercury, and most recently pharmaceuticals, may also affect this species. Reduced stream flow can have an impact of humpback chub populations. Researchers report that during reduced flows in Black Rocks, Westwater Canyon, Desolation/Gray Canyon, and Cataract Canyon the numbers of nonnative fishes and congener roundtail chub increase, potentially increasing effects of predation, competition, and hybridization. **We recommend that the Recovery Program implement a climate change initiative that outlines a strategy for dealing with the effects of drought, reduced stream flow, and associated effects in the context of recovery of the four endangered fishes.** Climate change effects may be detrimental or beneficial. Lowered levels of Lake Powell have exposed a greater reach of the canyon bound waters of Cataract Canyon and extended habitat for a possible expansion by that population of humpback chub. **We recommend investigations of the lower end of Cataract Canyon to determine if the population of humpback chub is expanding.**

Razorback Sucker

Critical biotic controlling factors that affect razorback sucker occur at the transition from embryos and larvae in substrate to dispersing larvae in the main channel and to larvae and juveniles in nursery floodplains. The importance of floodplains as nurseries to young razorback sucker has been recognized in only the last 2 decades. As with other species of pelagic larval drifters, predation on embryos and larvae in the substrate and in drift probably occurs, but it is assumed that this threat is minimized by the availability of quality floodplain habitats close to natal areas. The most critical of life stages to the razorback sucker is during occupation of nursery floodplains at ages 0-2. Several biotic controlling factors are critical, including predation, growth, food availability, competition, and effects of water quality on survival and growth. Numerous studies are being conducted under the Recovery Program that address these controlling factors and much valuable information is being gathered from these studies. **We believe that the current suite of studies and the direction they provide is adequate to address the controlling factors identified in the conceptual life history model for the razorback sucker.**

Efforts to augment the razorback sucker population with hatchery fish of various sizes has had some success, but survival of these young fish, as well as wild fish, continues to be low. Researchers agree that predation and competition by nonnative fish in floodplains is currently reducing survival of young razorback sucker and possibly impeding recovery of the species. Some advocate that floodplain-like habitats should be isolated and repatriated through removal of nonnative fish and stocking and rearing of razorback sucker to a size that exceeds the predator window. **The Recovery Program should continue to evaluate survival, growth, and recruitment of razorback sucker in floodplains to determine if this open-system approach will work or if a repatriation system will be necessary, such as implemented in the Lower Colorado River Basin.** On the Colorado and Gunnison rivers, identify spawning locations and proximity of floodplains that could be acquired. **In addition, continue the nonnative fish management element.**

A recent and increasing threat to all native sucker species in the Upper Colorado River Basin is increase and expansion of white sucker populations. The white sucker readily hybridizes with the native suckers, with the possibility of hybridizing with razorback sucker. Hybridization with flannelmouth and bluehead suckers in portions of the Yampa River and the Animas River has resulted in hybrid swarms in which few pure morphotypes remain. Hybridization with the white sucker could be the greatest threat to the razorback sucker as numbers of individuals increase from recovery efforts. **We recommend an assessment of the potential and extent of hybridization by the white sucker on flannelmouth and bluehead suckers and a strategic plan for control and removal of white sucker from the upper basin.**

The abiotic factors that affect the razorback sucker are associated with river flow, water quality (e.g., temperature, pollutants), channel geomorphology, blocked passage, and entrainment in canals. Flow recommendations for the Green River, Yampa River, White River, Gunnison River, and Upper Colorado River prescribe those flows and temperatures needed by the four species for recovery. Agreements among water users and the Recovery

Program provide for coordinated reservoir operations to meet target flows prescribed by these flow recommendations. **We urge the Recovery Program to continue coordinated operations to maintain important habitats and to promote floodplain health as a necessary component of razorback sucker recovery. However, water pollutants, especially selenium, mercury, and most recently pharmaceuticals, continue to have unknown affects on the four endangered fish species. We recommend continued**

support of efforts to evaluate effects of these pollutants to determine if remedial actions are necessary.

The threats of blocked passage and entrainment in canals are being addressed through construction of four fish passage structures and a fish screen on the largest canal in the upper basin. An overarching factor that may be having a large effect of fish populations in the upper basin is drought and more generally climate change. The effects of drought and climate change on the fishes of the upper basin are complex and the biotic and abiotic interactions cannot be easily assessed with a simple set of studies. **We recommend that the Recovery Program implement a climate change initiative that outlines a strategy for dealing with the effects of drought, reduced stream flow, and associated effects in the context of recovery of the four endangered fishes.**

Bonytail

So little is known about the life history and ecology of the bonytail in the naturalized rivers of the upper basin that it is difficult to fully assess research and monitoring needs to address biotic and abiotic controlling factors. Many of the same biotic controlling factors that affect razorback sucker apparently also affect the bonytail. Researchers currently believe that floodplain habitats may also be important to bonytail maintaining connectivity and functioning floodplains is important to the survival, growth, and recruitment by the species. However, the conceptual life history model presented in this document is only our best guess of the life history stages and controlling factors. We really don't know much about this species and why populations declined so precipitously in the 1960's—and why we continue to struggle with its recovery. Researchers have learned a great deal about the species in lower basin repatriated oxbows and ponds that can be applied to upper basin nursery floodplains. But the conditions needed by the species in the main channel continue to remain a mystery and only through close monitoring of stocked bonytail that survive over years can we understand the conditions needed for self-sustaining populations. **We recommend an annual assimilation and assessment of information on every stocked bonytail recaptured in the upper basin to better understand factors that affect survival, growth, and recruitment. Researchers should be requested to record for every fish at least: PIT tag number, length, weight, date, location, habitat type, observations of external parasites, and a general description of fish condition. The nonnative fish management element should be continued. We recommend the continued use of floodplains as a stocking location to determine if this action will increase their survival.** A concerted effort to recapture hatchery bonytail may be needed to determine survival after stocking, particularly in years when less activity is occurring on the rivers to better understand their life history needs and preferred habitats.

Recommendations

The following are recommended ongoing and new research activities that the Recovery Program should consider incorporating into the RIPRAP, based on the above evaluation of biotic and abiotic controlling factors. These recommendations were drawn from Tables 13-16. These research recommendations include only those activities that are not currently being addressed through existing or planned projects.

1. Continue to identify and address sources of mortality (e.g., predation and competition) for age-0 Colorado pikeminnow in nursery backwaters and develop strategies for reducing this threat. Activities related to this include non-native fish management, sampling under projects 22f, 138, the backwater data synthesis (FR-BW synth), and joint USFWS and UDWR, Vernal (project 158) sampling in backwaters in the middle Green River.

2. Continue to determine the most suitable summer and fall flows for age-0 Colorado pikeminnow nursery backwater formation. Activities related to this include sampling under projects 22f, 138, the backwater and geomorphic data synthesis (FR-BW synth), and joint USFWS and UDWR, Vernal sampling in backwaters in the middle Green River (project 158).

3. Continue to identify and address sources of mortality (e.g., predation and competition) for late age-0 and age-1 Colorado pikeminnow after they leave the nursery backwaters and develop strategies for reducing this threat. Aspects of this are being investigated under projects 22f, 138, FR-BW, and pikeminnow abundance estimation efforts, which link recruitment and relative abundance at early life stages with juveniles, recruits, and adults. Other modeling tools are also available to investigate this further, including an individual-based recruitment model for Colorado pikeminnow.

4. Continue to implement innovative techniques to evaluate the effectiveness of nonnative fish management, such as recruitment models to help assess the necessary reduction levels of nonnative fishes, as well as the effectiveness of these actions on the endangered fishes. Aspects of this are being developed by ongoing non-native fish management workshops and work conducted under project 161, the smallmouth bass data synthesis, and recruitment analyses conducted in conjunction with abundance estimates. Additional intensive sampling to disrupt smallmouth bass reproduction is being conducted in the Yampa River in 2010 (projects 98 and 125, as are investigations of the most efficient electrofishing gear [project 147]). Ongoing investigations to assess timing of spawning and hatching of smallmouth bass in the Green and Yampa rivers (projects 115 and 140) may also assist with development of strategies to reduce their reproductive success via dam operations at Flaming Gorge.

5. Implement a climate change initiative that outlines a strategy for dealing with the effects of drought, reduced stream flow, and associated effects in the context of

recovery of the four endangered fishes. Climate change initiatives should also assess effects on invasive species, and their potential interactions with natives. . Such work is being considered under the Southern Rockies Landscape Conservation Cooperative (LCC) but other sources of support should also be investigated.

6. Continue to evaluate the effects of water pollutants, including selenium, mercury, and pharmaceuticals on the four endangered fish species. The Recovery Program continues to support activities associated with toxicant and pollutant studies (mercury, selenium, and pharmaceuticals) which is generally conducted by other agencies such as the Environmental Protection Agency, USGS, Reclamation (e.g., Selenium Management Plan in the Gunnison River subbasin), and the states under their respective water quality plans (e.g., Stewart Lake selenium remediation).

7. Identify and address sources of mortality (e.g., predation and competition) for age-0 humpback chub in nursery habitats. Aspects of this are being investigated via non-native fish management activities in reaches where chubs occur, projects 115 and 161, and through ongoing non-native fish workshops.

8. Identify and address sources of mortality (e.g., predation and competition) for age-1 humpback chub in rearing habitat. Aspects of this are being investigated via non-native fish management activities in reaches where chubs occur, projects 115 and 161, and through ongoing non-native fish workshops.

9. Develop a strategic plan for control and removal of white sucker from the upper basin. Ongoing studies include assessment of white sucker hybridization and abundance patterns related to flows and water temperatures (project 115), removal of white sucker from some reaches being conducted in an experimental framework (State of Utah’s 3 spp. efforts, projects 115 and 125), and consideration of those effects in range-wide “3 species” investigations.

10. Continue to assimilate and assess information on all stocked endangered fish recaptured in the upper basin to better understand factors that affect survival, growth, and recruitment. Ongoing aspects of this include database management activities, assessment of survival rates of stocked and recaptured razorback sucker in the Upper Colorado River Basin (project 159).

Other Issues

The RIPRAP is an important document to the Recovery Program that does a good job of identifying important activities for each of the five program elements for the upper basin. There are however, controlling issues that cannot necessarily be addressed through a RIPRAP, but may have a significant effect on the Recovery Program and its activities. These issues are not unique to the Upper Basin Recovery Program and identifying these in this document should not be viewed as a criticism of the Recovery Program, its partners, or their staffs, but rather a recognition these issues exist. These issues are identified to assist the Recovery Program and to acknowledge that effective recovery spans beyond the scope of research and monitoring projects.

Database Integration and Utilization

With formation of the Recovery Program in 1988, a system of database centralization and report compilation began that continues today. The data stored in this centralized database include a variety of datasets collected under a variety of objectives and sampling designs. Beginning in 1991, the database established a standardized PIT tag dataset from which investigators can track capture and recapture information of individual fishes. Prior to the advent of PIT tags, other less adequate tagging techniques with high tag loss were used. Most of the data contained in the database starts in 1986, which was the beginning of the ISMP. Also included in the database are data collected under the CRFP from 1978 to 1988. Data collected prior to 1978 (i.e., 1962–1978) have been entered into an electronic database as part of a project coordinated by the Colorado River Water Congress. These data were stored on an electronic tape (two copies were made) in the old VAX computer format. The Recovery Program should obtain this tape and include these data in the Upper Basin database. Another dataset that contains valuable information on fish communities from 1999 to 2003 was gathered by the Colorado Division of Wildlife (Anderson and Stewart 2006).

These data are stored on large hard drives and were recently transferred to SWCA as part of this project. These data should also be incorporated into the Upper Basin database.

Some investigators have recently conducted more robust analyses by including prior data that better help to explain recent population patterns or cohort strengths (e.g., Bestgen et al. 2005, 2007; Osmundson and White 2009, Bestgen et al. 2010, project 138). More integration of reliable historical data and other environmental parameters is ongoing (project FR-BW) and more should be encouraged.

Consistency and Training of Research Personnel

Although much of fisheries research is a scientific endeavor, there is an element of investigations at both the field collection stage and data analysis that requires a certain amount of experience and intuition. Although sampling designs may seem straight-forward on paper, they are often fraught with pitfalls and logistical problems that demand smart decisions to be made afield. Weather, unpredictable river conditions, equipment breakdowns, schedule changes, etc. may require a field investigator to adjust data collection that may affect the outcome of an analysis. Making these decisions so that data results are comparable and meaningful requires experienced investigators who have undergone this process of field data collection and analysis in the past.

Virtually all of the fisheries monitoring in the upper basin is done by field offices of either state or federal agencies. These offices are staffed with Project Leaders, a small number of senior biologists, and junior biologists that are hired on an annual basis. Although most field crews consist of at least one senior biologist, sometimes these crews may consist entirely of junior biologists, especially as the field season progresses and these individual are viewed to be "more experienced". Most of these agencies have a fairly high turnover of Project Leaders and senior and junior biologists that often results in a hiatus of experience. Outgoing leaders and biologists should provide detailed information on projects they were responsible for in order that new personnel will have a good understanding when taking over similar projects.

The Recovery Program recently collaborated with the Colorado Water Conservation Board to convert the Program's library to laserfiche format and make it available on CWCB's website. We encourage this and any effort that facilitates access to the body of information that has been gathered throughout the life of the Program so that it can be used to guide informed future research.

Standardization of Gear Types

A variety of gears has been—and is being—employed to sample fishes in the Upper Colorado River Basin. The gears used for monitoring have become fairly standardized and include boat electrofishers for Colorado pikeminnow, trammel nets for humpback chub, small-mesh seines for age-0 Colorado pikeminnow, and drift nets for larvae. The Recovery Program and the investigators are encouraged to communicate regularly in order to standardize sampling gears and protocols so that variance and biases are reduced as much as possible. This should not, however, discourage the use of new gears or sampling methods (e.g., remote PIT tag antennas) that may be more efficient or effective for a particular species or life stage, provided a link is made to the older methods that may get replaced. The Recovery Program and the CDOW are to be commended for standardizing the hard-bottom boat fleet (Martinez and Kolz 2009) and implementing an annual check of electrofishing boats in the upper basin to ensure gear standardization, maximum capture efficiency, user safety, and minimum harm to the fish. All investigators involved in monitoring should thoroughly check their gear and communicate with colleagues to ensure consistency in gear types and methodologies. Electrofisher testing and standardization is ongoing.

Alternative Nonnative Fish Management Paradigms

There are fundamentally two alternative and sometimes competing nonnative fish management paradigms in the Colorado River System, based on the universally accepted premise that nonnative fish species negatively affect native species and inhibit recovery of the endangered fishes. The first paradigm is embraced by the Upper Basin Recovery Program and is based on the belief that native fishes can exist sympatrically with nonnative species if habitat is suitable and active management continues to suppress nonnative forms to sufficiently low levels in key locations (i.e., open system).

The second paradigm has been implemented in parts of the lower basin (USFWS 2005) and does not accept the premise that native and nonnative fish species can coexist and proposes isolation and repatriation of oxbows or floodplains for rearing young fish to a size not susceptible to predation (i.e., closed system). The Recovery Program continues to release hatchery razorback sucker and bonytail into connected floodplains for rearing in habitats also occupied by a variety of nonnative fishes. Some of these fish are preyed upon by nonnative fishes, but some are also surviving and recruiting to the adult population. This approach should continue to be evaluated to ensure that the open system paradigm is effective for species recovery.

Basis for Scientific Inference from Field Studies

Most scientists remind the public that science is the process of gathering information by which to make informed decisions and use their professional judgment. Sometimes, competing hypotheses cannot be distinguished by a single unambiguous test, but only by a suite of tests of different kinds, that produce a body of evidence to support one line of argument and not others (Holling 1996; Holling and Allen 2002). This process is called "adaptive inference". Instead of pitting each member of a pair of hypotheses against each other, adaptive inference relies on multiple, competing hypotheses, after which carefully structured comparative data are used to explore the logical consequences of each. This approach is similar to the weight-of-evidence approach in which multiple pieces of information are used to derive a reasonable explanation (Beyers 1998). Accordingly, upper basin scientists should design their research and/or monitoring to provide for multiple data analyses and cross-checks that provide more than one line of evidence and do not trap an investigator into relying on a single hypothesis test.

Population Estimates in Perspective

Most mark-recapture population estimates in the upper basin have been done in the last decade and most populations of Colorado pikeminnow and humpback chub have only one or two 3-year cycles of estimates. For those species, which have long generation times, the few estimates available are insufficient to convey the dynamics of population patterns. Populations of these species can be expected to vary year-to-year and certainly over decades, and it would be unusual and biologically unrealistic to expect these populations to remain relatively stable over time, but rather have some sinusoidal pattern over long time periods. The dynamic patterns of these populations are unknown, and precise and accurate population estimates will have to continue for possibly at least two or three species generations in order to begin to understand the natural fluctuations of these populations. Therefore, caution and patience in interpreting wide swings in population abundance needs to be prudent. Scientists should focus on understanding the dynamics of these fish populations in order to be able to distinguish natural population fluctuations from threat-induced declines. Appropriate management decisions and actions are required when the multiple lines of evidence indicate a true decline that could jeopardize the population.

Recovery Program Limitations

We have concluded that the RIPRAP provides a comprehensive list of those activities that are necessary for recovering the four Colorado River endangered fishes. We also conclude that the Recovery Program is generally doing a good job of administrating, coordinating, and executing specific projects that address species threats. We did not find glaring oversights or gaps in monitoring and/or research activities, nor did we identify unnecessary activities or projects. In the previous sections, we have described information needs and recommendations for new research. The biggest information need is a determination of what affects survival of early life stages of all four species. The strength of a cohort sets the stage for future reproductive potential and eventually for population size and growth. We recognize, however, that finding and following the fate of these small young fish is not easy and may not be feasible, given the logistical difficulty of sampling in remote areas under arduous conditions. We do, however, urge the Recovery Program to continue to investigate new strategies and analytical techniques for assessing growth and survival of these young fish—and more importantly, the most significant controlling factors and appropriate remedial actions.

LITERATURE CITED

Anderson, R. 1998. Riverine fish-flow investigations. Federal Aid Project F-288, Colorado Division of Wildlife, Fort Collins, Colorado.

Anderson, R., and G. Stewart. 2006. Impacts of stream flow alterations on native fish abundance and native fish habitat and the use of native fish population data to support instream flow recommendations made with a 2d instream methodology. Colorado Division of Wildlife, Grand Junction, Colorado.

Badame, P.V. 2008. Population estimates for humpback chub (*Gila cypha*) in Cataract Canyon, Colorado River, Utah, 2003–2005. Final Report of Utah Division of Wildlife Resources to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado

Badame, P.V. 2009. Population estimate for humpback chub (*Gila cypha*) in Desolation and Gray Canyons, Green River, Utah, 2006–2007. Final Report of Utah Division of Wildlife Resources to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Badame, P.V., and M. Hudson. 2001. Reintroduction and monitoring of hatchery-reared bonytail in the Colorado and Green rivers: 1996–2001. Final Report of Utah Division of Wildlife Resources to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Bestgen, K. R. 1990. Status review of the razorback sucker, *Xyrauchen texanus*. Final Report to U. S. Bureau of Reclamation, Salt Lake City, Utah. Colorado State University Larval Fish Laboratory Contribution 44.

Bestgen, K. R. 1996. Growth, survival, and starvation resistance of Colorado squawfish larvae. Environmental Biology of Fishes 46: 197–209.

Bestgen, K. R., and G.B. Haines. 2010. Synthesis of flood plain wetland information: timing of razorback sucker reproduction in the Green River, Utah, related to stream flow, water temperature, and flood plain wetland availability. Draft Final Report to Upper Colorado River Endangered Fish Recovery Program, De3nver, Colorado.

Bestgen, K. R., and M. A. Williams. 1994. Effects of fluctuating and constant temperatures on early development and survival of Colorado squawfish. Transactions of the American Fisheries Society 123: 574–579.

Bestgen, K. R., D. W. Beyers, G. B. Haines, and J. A. Rice. 1997. Recruitment models for Colorado squawfish: tools for evaluating relative importance of natural and managed processes. Final Report to U.S. National Park Service Cooperative Parks Study Unit and U.S. Geological Survey Midcontinent Ecological Science Center, Fort Collins, Colorado. Larval Fish Laboratory Contribution 95, Colorado State University, Fort Collins.

Bestgen, K.B., R.T. Muth and M.A. Trammel. 1998. Downstream transport of Colorado squawfish larvae in the Green River drainage: temporal and spatial variation in abundance and relationships with juvenile recruitment. Final Report of Colorado State University larval Fish Laboratory to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Bestgen, K. R., G. B. Haines, R. Brunson, T. Chart, M. Trammell, G. Birchell, and K. Christopherson. 2002. Status of wild razorback sucker in the Green River Basin, Utah and Colorado, determined from basinwide monitoring and other sampling programs. Final report submitted to the Recovery Implementation Program for Endangered Fishes in the Upper Colorado River Basin, Denver, Colorado. Larval Fish Laboratory Contribution 126.

Bestgen, K. R., J. A. Hawkins, G. C. White, K. Christopherson, M. Hudson, M. Fuller, D. C. Kitcheyan, R. Brunson, P. Badame, G. B. Haines, J. Jackson, C. D. Walford, T. A. Sorensen, and T. B. Williams. 2005. Population status of Colorado pikeminnow in the Green River Basin, Utah and Colorado. Final report submitted to the Recovery Implementation Program for Endangered Fishes in the Upper Colorado River Basin, Denver, Colorado. Larval Fish Laboratory Contribution 140, Colorado State University, Fort Collins.

Bestgen, K. R., D. W. Beyers, J. A. Rice, and G. B. Haines. 2006a. Factors affecting recruitment of young Colorado pikeminnow: synthesis of predation experiments, field studies, and individual-based modeling. Transactions of the American Fisheries Society 135: 1722–1742.

Bestgen, K. R., K. A. Zelasko, R. I. Compton, and T. Chart. 2006b. Response of the Green River fish community to changes in flow and temperature regimes from Flaming Gorge Dam since 1996 based on sampling conducted from 2002 to 2004. Final report, Upper Colorado River Basin Endangered Fish Recovery Program, Denver, Colorado. Larval Fish Laboratory Contribution 144, Colorado State University, Fort Collins.

Bestgen, K. R., J. A. Hawkins, G. C. White, K. Christopherson, M. Hudson, M. Fuller, D. C. Kitcheyan, R. Brunson, P. Badame, G. B. Haines, J. Jackson, C. D. Walford, and T. A. Sorensen. 2007. Population status of Colorado pikeminnow in the Green River Basin, Utah and Colorado. Transactions of the American Fisheries Society 136: 1356–1380.

Bestgen, K.R., K.A. Zelasko, R.I. Compton, and T.E. Chart. 2008. Survival, condition, habitat use, and predation of stocked bonytail in the Green River, Colorado and Utah. Southwestern Naturalist **53**: 488–494.

Bestgen, K.R., J.A. Hawkins, G.C. White, C.D. Walford, P. Badame, and L. Monroe. 2010. Population status of Colorado pikeminnow in the Green River Basin, Utah and Colorado, 2006-2008. Final Report of the Larval Fish Laboratory, Colorado State University to the Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Beyers, D.W. 1998. Causal inference in environmental impact studies. Journal of the North American Benthological Society 17: 367–373.

Breen, M.J., M. Swasey, T.N. Hedrick, P. Badame, and K. Creighton. 2010. Upper Colorado River basin young-of-year Colorado pikeminnow (Ptychocheilus lucius) monitoring: summery report 1986–2009. Draft Report to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Burdick, B.D., and R.B. Bonar. 1997. Experimental stocking of adult razorback sucker in the upper Colorado and Gunnison Rivers. U.S. Fish and Wildlife Service, Grand Junction, Colorado.

Chart, T. E., and L. D. Lentsch. 1999. Reproduction and recruitment of *Gila* spp. and Colorado pikeminnow (*Ptychocheilus lucius*) in the middle Green River 1992–1996. Report C *in* Flaming Gorge Studies: Reproduction and recruitment of *Gila* spp. and Colorado pikeminnow (*Ptychocheilus lucius*) in the middle Green River. Draft Final Report of Utah Division of Wildlife Resources to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Chart, T.E., D. Svendson, and L. Lentsch. 1999. Investigation of potential razorback sucker (*Xyrauchen texanus*) and Colorado pikeminnow (*Ptychocheilus lucius*) spawning in the lower Green River 1994 and 1995. Final Report of Utah Division of Wildlife Resources to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Christopherson, K. D., G. J. Birchell, and T. Modde. 2005. Larval razorback sucker and bonytail survival and growth in the presence of nonnative fish in the Stirrup floodplain. Final report to the Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado. Utah Division of Wildlife Resources, Publication 05-04, Salt Lake City, Utah.

Converse, Y.K., C.P. Hawkins, and R.A. Valdez. 1998. Habitat relationships of subadult humpback chub in the Colorado River through Grand Canyon: spatial variability and implications of flow regulation. Regulated Rivers 14: 267–284.

Dowling, T.E., and B.D. DeMarais. 1993. Evolutionary significance of introgressive hybridization in cyprinid fishes. Nature 362: 444–446.

Elverud, D. 2008. Population estimate of humpback chub in Westwater Canyon. Annual project report, Project No. 132. Upper Colorado River Endangered Fish Recovery Program, Moab, Utah.

Finney, S. 2006. Adult and Juvenile Humpback Chub Monitoring for the Yampa River Population, 2003-2004. Final report of U.S. Fish and Wildlife Service to the Recovery Implementation Program for Endangered Fishes in the Upper Colorado River Basin, Denver, Colorado.

Francis, T.A., and C.W. McAda. 2010. Population size and structure of humpback and roundtail chub, *Gila cypha* and *robusta*, in Black Rocks, Colorado River, Colorado, 2007–2008. Draft report submitted to the Recovery Implementation Program for Endangered Fishes in the Upper Colorado River Basin, Denver, Colorado, by the U. S. Fish and Wildlife Service, Grand Junction, Colorado.

Gorman, O.T., and D.M. Stone. 1999. Ecology of spawning humpback chub, *Gila cypha*, in the Little Colorado River near Grand Canyon, Arizona. Environmental Biology of Fishes 55: 115–133.

Gutermuth, F. B., L. D. Lentsch, and K. R. Bestgen. 1994. Collection of age-0 razorback suckers (*Xyrauchen texanus*) in the lower Green River, Utah. Southwestern Naturalist 39: 389–391.

Haines, G. B., and H. M. Tyus. 1990. Fish associations and environmental variables in age–0 Colorado squawfish habitats, Green River, Utah. Journal of Freshwater Ecology 5:427–436.

Haines, G. B., D. W. Beyers, and T. Modde. 1998. Estimation of winter survival, movement, and dispersal of young Colorado squawfish in the Green River, Utah. Final Report of U.S. Fish and Wildlife Service, Vernal, Utah, to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Harvey, M. D., R. A. Mussetter, and E. J. Wick. 1993. A physical process biological-response model for spawning habitat formation for the endangered Colorado squawfish. Rivers 4: 114–131.

Haynes, C. M., T. A. Lytle, E. J. Wick, and R. T. Muth. 1984. Larval Colorado squawfish (*Ptychocheilus lucius*) in the Upper Colorado River Basin, Colorado, 1979–1981. Southwestern Naturalist 29:21–33.

Holling, C.S. 1996. Two cultures of ecology. Conservation Ecology. Editorial.

Holling, C.S., and C.R. Allen. 2002. Adaptive inference for distinguishing credible from incredible patterns in nature. Ecosystems 5: 319–328.

Hudson, J.M., and J.A. Jackson. 2003. Population estimates for humpback chub (*Gila cypha*) and roundtail chub (*Gila robusta*) in Westwater Canyon, Colorado River, Utah, 1998–2000. Final Report of Utah Division of Wildlife Resources to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Irving, D., and T. Modde. 2000. Home-range fidelity and use of historical habitat by adult Colorado squawfish *(Ptychocheilus lucius*) in the White River, Colorado and Utah. Western North American Naturalist 60: 16–25.

Jackson, J. 2004. Westwater Canyon humpback chub population estimates. Utah Division of Wildlife Resources. Presentation at Population Estimates Workshop II, August 24–25, 2004, Grand Junction, Colorado.

Jackson, J.A., and J.M. Hudson. 2005. Population estimate for humpback chub (*Gila cypha*) in Desolation and Gray Canyons, Green River, Utah 2001-2003. Final Report of Utah Division of Wildlife Resources to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Kaeding, L. R., B. D. Burdick, P. A. Schrader, and W. R. Noonan. 1986. Recent capture of a bonytail (*Gila elegans*), and observations on this nearly extinct cyprinid from the Colorado River. Copeia 1986: 1021–1023

Kaeding, L. R., B. D. Burdock, P. A. Schrader, and C. W. McAda. 1990. Temporal and spatial relations between the spawning of humpback chub and roundtail chub in the Upper Colorado River. Transactions of the American Fisheries Society 119: 135–144.

LaGory, K. E., J. W. Hayse, and D. Tomasko. 2003. Recommended priorities for geomorphology research in endangered fish habitats of the Upper Colorado River Basin. Final Report, Recovery Program Project 134. September 2003.

Lanigan, S. H., and H. M. Tyus. 1989. Population size and status of razorback sucker in the Green River basin, Utah and Colorado. North American Journal of Fisheries Management 9: 68–73.

Marsh, P. C., C. A. Pacey, and B. R. Kesner. 2003. Decline of the razorback sucker in Lake Mohave, Colorado River, Arizona and Nevada. Transactions of the American Fisheries Society 132: 1251–1256.

Martinez, P.J., and A.L. Kolz. 2009. Evaluating the power output of the Smith-Root GPP 5.0 Electrofisher to promote electrofishing fleet standardization. North American Journal of Fisheries Management 29: 570–575.

McAda, C.W. 2002. Population size and structure of humpback chub in Black Rocks, 1998–2000. Final report of U.S. Fish and Wildlife Service to the Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

McAda, C.W. 2003. Flow Recommendations to Benefit Endangered Fish in the Colorado and Gunnison Rivers. Final report of U.S. Fish and Wildlife Service to the Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

McAda, C.W. 2004. Population estimate of humpback chub in Black Rocks. Annual report Project Number 131 to the Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

McAda, C.W. 2006. Population estimate of humpback chub in Black Rocks. Annual report Project Number 131 to the Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

McAda, C. W., and L. R. Kaeding. 1989. Relations between maximum-annual river discharge and the relative abundance of age-0 Colorado squawfish and other fishes in the Upper Colorado River. U.S. Fish and Wildlife Service, Grand Junction, Colorado.

Minckley, W. L. 1983. Status of the razorback sucker, *Xyrauchen texanus* (Abbott), in the lower Colorado River basin. Southwestern Naturalist 28: 165–187.

Minckley, W. L., P. C. Marsh, J. E. Brooks, J. E. Johnson, and B. L. Jensen. 1991. Management toward recovery of the razorback sucker. Pages 303–357 *in* W. L. Minckley and J. E. Deacon, editors. Battle against extinction: native fish management in the American West. University of Arizona Press, Tucson.

Modde, T. 1996. Juvenile razorback sucker (*Xyrauchen texanus*) in a managed wetland adjacent to the Green River. Great Basin Naturalist 56: 375–376.

Modde, T., and G. Smith. 1995. Flow recommendations for endangered fish in the Yampa River. Final report of the U.S. Fish and Wildlife Service to the Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Modde, T., and D. B. Irving. 1998. Use of multiple spawning sites and seasonal movements by razorback suckers in the middle Green River, Utah. North American Journal of Fisheries Management 18: 318–326.

Modde, T. and C. Keleher. 2003. Flow recommendations for the Duchesne River with a synopsis of information regarding endangered fishes. Report of U.S. Fish and

Wildlife Service to the Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Modde, T., and G. B. Haines. 2005. Survival and growth of stocked razorback sucker and bonytail in multiple floodplain wetlands of the middle Green River under reset conditions. Final Report of U.S. Fish and Wildlife Service to the Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Modde, T., K.P. Burnham, and E.J. Wick. 1996. Population status of the razorback sucker in the middle Green River. Conservation Biology 10: 110–119.

Modde, T., W.J. Miller, and R. Anderson. 1999. Determination of habitat availability, habitat use, and flow needs of endangered fishes in the Yampa River between August and October. Final Report to Upper Colorado River Endangered Fish Recovery Program. Denver, Colorado.

Mueller, G.A. 2006. Ecology of bonytail and razorback sucker and the role of off-channel habitats in their recovery. U.S. Geological Survey, Fort Collins Science Center. Scientific Investigations Report 2006-5065, Fort Collins, Colorado.

Muth, R.T., G.B. Haines, S.M. Meismer, E.J. Wick, T.E. Chart, D.E. Snyder, and J.M. Bundy. 1998. Reproduction and early life history of razorback sucker in the Green River, Utah and Colorado, 1992–1996. Final Report of Colorado State University Larval Fish Laboratory to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Muth, R.T., L.W. Crist, K.E. LaGory, J.W. Hayse, K.R. Bestgen, T.P. Ryan, J.K. Lyons, and R.A. Valdez. 2000. Flow and temperature recommendations for endangered fishes in the Green River downstream of Flaming Gorge Dam. Final Report FG-53 to the Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Nesler, T.P., R.T. Muth, and A.F. Wasowicz. 1988. Evidence for baseline flow spikes as spawning cues for Colorado squawfish in the Yampa River, Colorado. American Fisheries Society Symposium 5: 68–79.

Osmundson, D.B. 2000. Monitoring the Colorado pikeminnow population in the mainstem Colorado River via periodic population estimates. Annual Report of U.S. Fish and Wildlife Service, Grand Junction, Colorado, to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Osmundson, D.B. 2003. Monitoring the Colorado pikeminnow population in the mainstem Colorado River via periodic population estimates. Annual Report of U.S. Fish and Wildlife Service, Grand Junction, Colorado, to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Osmundson, D.B. 2004. Colorado pikeminnow population estimation: Recent results - 2003 & 2004, Upper Colorado River. U.S. Fish and Wildlife Service. Presentation at Population Estimates Workshop II, August 24–25, 2004, Grand Junction, Colorado.

Osmundson, D.B. 2005. Monitoring the Colorado pikeminnow population in the mainstem Colorado River via periodic population estimates. Annual Report of U.S. Fish and Wildlife Service, Grand Junction, Colorado, to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Osmundson, D.B. 2006. Proximate causes in sexual size dimorphism in Colorado pikeminnow, a long-lived cyprinid. Journal of Fish Biology 68: 1563–1588.

Osmundson, D.B., and L.R. Kaeding. 1989. Studies of Colorado squawfish and razorback sucker use of the '15-Mile Reach' of the Upper Colorado River as part of conservation measures for the Green Mountain and Ruedi Reservoir water sales. Final Report of U.S. Fish and Wildlife Service, Grand Junction, Colorado.

Osmundson, D.B., and L.R. Kaeding. 1991. Recommendations for flows in the 15-mile reach during October–June for maintenance and enhancement of endangered fish populations in the Upper Colorado River. Final Reportof U.S. Fish and Wildlife Service, Grand Junction, Colorado.

Osmundson, D.B., P. Nelson, K. Fenton, and D.W. Ryden. 1995. Relationship between flow and rare fish habitat in the '15-mile reach' of the Upper Colorado River. Final Report of the U.S. Fish and Wildlife Service, Grand Junction, Colorado.

Osmundson, D. B., and K. Burnham. 1998. Status and trends of the endangered Colorado squawfish in the Upper Colorado River. Transactions of the American Fisheries Society 127: 957–970.

Osmundson, D.B., and S.C. Seal. 2010. Successful spawning by stocked razorback sucker in the Gunnison and Colorado rivers, as evidenced by larval fish collections, 2002–2007. Final Draft Report of U.S. Fish and Wildlife Service to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Osmundson, D.B., and G.C. White. 2009. Population Status and Trends of Colorado Pikeminnow of the Upper Colorado River, 1991–2005. Final Report to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Osmundson, D. B., R. J. Ryel, and T. E. Mourning. 1997. Growth and survival of Colorado squawfish in the Upper Colorado River. Transactions of the American Fisheries Society 126:687–698.

Osmundson, D. B., R. J. Ryel, M. E. Tucker, B. D. Burdick, W. R. Elmblad, and T. E. Chart. 1998. Dispersal patterns of subadult and adult Colorado squawfish in the Upper Colorado River. Transactions of the American Fisheries Society 127:943–956.

Ruppert, J. B., R. T. Muth, and T. P. Nesler. 1993. Predation on fish larvae by adult red shiner, Yampa and Green rivers, Colorado. Southwestern Naturalist 38:397–399.

Snyder, D.E., K.R. Bestgen, D.L. Davis, and S.T. Finney. 2006. Taxonomic analysis of early juvenile *Gila* from Yampa Canyon, Dinosaur National Monument. Poster paper presented at Annual Meeting of the Colorado/Wyoming Chapter of the American Fisheries Society, 6-9 March, 2006, Cheyenne, Wyoming.

Thompson, J.M., E.P. Bergersen, C.A. Carlson, and L.R. Kaeding. 1991. The role of size, condition, and lipid content in the overwinter survival of age-0 Colorado squawfish. Transactions of the American Fisheries Society 120: 346–353.

Tyus, H.M. 1987. Distribution, reproduction, and habitat use of the razorback sucker in the Green River, Utah, 1979–1986. Transactions of the American Fisheries Society 116: 111–116.

Tyus, H.M. 1990. Potamodromy and reproduction of Colorado squawfish in the Green River basin, Colorado and Utah. Transactions of the American Fisheries Society 119: 1035–1047.

Tyus, H.M., and C.A. Karp. 1989. Habitat use and streamflow needs of rare and endangered fishes, Yampa River, Colorado and Utah. U.S. Fish and Wildlife Service Biological Report 89: 1–27.

Tyus, H.M., and C.A. Karp. 1990. Spawning and movements of razorback sucker, *Xyrauchen texanus*, in the Green River basin of Colorado and Utah. Southwestern Naturalist 35: 427–433.

Tyus, H.M., and G.B. Haines. 1991. Distribution, habitat use, and growth of age–0 Colorado squawfish in the Green River basin, Colorado and Utah. Transactions of the American Fisheries Society 120: 79–89.

U.S. Fish and Wildlife Service. 1992. Final Biological Opinion on operation of Flaming Gorge Dam. Fish and Wildlife Service, Mountain-Prairie Region, Denver, Colorado.

U.S. Fish and Wildlife Service. 2002a. Colorado Pikeminnow (*Ptychocheilus lucius*) Recovery Goals: Amendment and supplement to the Colorado Squawfish Recovery Plan. U.S. Fish and Wildlife Service, Mountain-Prairie Region (6), Denver, Colorado.

U.S. Fish and Wildlife Service 2002b. Humpback Chub (*Gila cypha*) Recovery Goals: Amendment and supplement to the Humpback Chub Recovery Plan. U.S. Fish and Wildlife Service, Mountain-Prairie Region (6), Denver, Colorado.

U.S. Fish and Wildlife Service 2002c. Razorback Sucker (*Xyrauchen texanus*) Recovery Goals: Amendment and supplement to the Razorback Sucker Recovery Plan. U.S. Fish and Wildlife Service, Mountain-Prairie Region (6), Denver, Colorado.

U.S. Fish and Wildlife Service. 2002d. Bonytail (*Gila elegans*) Recovery Goals: Amendment and supplement to the Bonytail Chub Recovery Plan. U.S. Fish and Wildlife Service, Mountain-Prairie Region (6), Denver, Colorado.

U.S. Fish and Wildlife Service. 2009. Management plan for the big-river fishes of the Lower Colorado River Basin: amendment and supplement to the bonytail, humpback chub, Colorado pikeminnow, and razorback sucker recovery plans.

U.S. Fish and Wildlife Service. 2009. Part One: Section 7 Consultation, Sufficient Progress, and Historic Projects Agreement; and Part Two: Recovery Implementation Program Recovery Action Plan. Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Valdez, R.A. 1990. The endangered fish of Cataract Canyon. Final Report of BIO/WEST, Inc. to U.S. Bureau of Reclamation, Salt Lake City, Utah.

Valdez, R.A., and G.C. Clemmer. 1982. Life history and prospects for recovery of the humpback and bonytail chub. Pages 109–119 *in* W.H. Miller, H.M. Tyus, and C.A. Carlson, editors. Fishes of the Upper Colorado River system: present and future. Western Division, American Fisheries Society, Bethesda, Maryland.

Valdez, R.A., and R.J. Ryel. 1995. Life history and ecology of the humpback chub (*Gila cypha*) in the Colorado River, Grand Canyon, Arizona. Final Report of Bio/West, Inc., Logan, Utah, to U.S. Bureau of Reclamation, Salt Lake City, Utah.

Valdez, R.A., and T.L. Hoffnagle. 1999. Movement, habitat use, and diet of adult humpback chub. Pages 297–307 *in* R.H. Webb, J.C. Schmidt, G.R. Marzolf, and R.A. Valdez (eds.). The controlled flood in Grand Canyon. Geophysical Monograph 110. American Geophysical Union, San Francisco, California.

Valdez, R.A., and P. Badame. 2005. Humpback chub population estimate in Cataract Canyon, Colorado River, Utah. Annual Report Project 130 to Upper Colorado River Recovery Program, Denver, Colorado.

Valdez, R.A., and P. Nelson. 2004. Floodplain management plan for the Green River subbasin. Final Report to Upper Colorado River Recovery Implementation Program, Denver, Colorado.

Valdez, R.A., and R.T. Muth. 2005. Ecology and conservation of native fish in the Upper Colorado River Basin. Pages 157–204 i*n* Rinne, J.N., R.M. Hughes, and B. Calamusso (eds.). Historical changes in large river fish assemblages of the Americas. American Fisheries Society Symposium 45.

Valdez, R.A., and P. Nelson. 2006. Upper Colorado River Subbasin floodplain management plan. Final Report to Upper Colorado River Recovery Implementation Program, Denver, Colorado.

Valdez, R.A., P. Mangan, R. Smith, B. Nilson. 1982. Upper Colorado River investigations (Rifle, Colorado to Lake Powell, Utah). Pages 100–279 *in* U.S. Fish and Wildlife Service. Colorado River Fishery Project, Final Report, Part 2: Field Investigations. U.S. Fish and Wildlife Service, Salt Lake City, Utah.

Zelasko, K., K. Bestgen, and G. White. 2009. Survival rate estimation and movement of hatchery-reared razorback sucker *Xyrauchen texanus* in the Upper Colorado River Basin, Utah and Colorado. Final Report of Colorado State University to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.