Nonnative Fish in Grand Canyon – Summary of Nonnative Fish Control Options and Recommended Monitoring and Research Activities

By Kara D. Hilwig, Matthew E. Andersen, and Lewis G. Coggins, Jr.

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
mile (mi)	1.609	kilometer (km)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Mass	
kilogram (kg)	2.205	pound avoirdupois (lb)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32

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By Kara D. Hilwig, Matthew E. Andersen, and Lewis G. Coggins, Jr.[1]

Preface

On August 11, 2004 the AMWG passed the following motion: "That GCMRC and TWG make a recommendation to AMWG in October 2004 on warm water species studies including a plan starting in January 2005". Subsequently on September 27, 2004 the TWG passed an additional motion: "GCMRC will develop a process, a schedule, and a recommended budget for suppression and control of non-native fish (warm water species) to be presented to AMWG…". This document represents US Geological Survey (USGS) Grand Canyon Monitoring and Research Center's (GCMRC) effort to meet the intent of this motion. Here we present options for nonnative fish control and recommendations for monitoring and research following extensive reviews of literature and available data. This document is responsive to concerns brought forth during multiple reviews of this document from scientists, resource managers, the Tribes, and other stakeholders. These reviews modified the content of the document beyond the original AMWG motion and more towards an ecosystem approach to evaluating and addressing nonnative fish issues in Grand Canyon. GCMRC feels the progression and content of this document represents technically sound options for control of nonnative fish species and recommendations for addressing nonnative fish monitoring and research needs in Grand Canyon. Thus, this document provides the technical foundation for management agencies with statutory authority to initiate the development of a comprehensive management plan nonnative fishes for Grand Canyon. This document is not a management plan and is not intended to obligate management agencies or the AMP to implement any research or monitoring recommendations or control options presented herein. Implementation of control options presented in this document will be carried out in compliance with management agency policies, mandates, and tribal consultation requirements. This includes, but is not limited to, the requirements associated with the Endangered Species Act, National Environmental Policy Act, National Historic Preservation Act and Federal-Tribal Trust Responsibilities. Necessary compliance for the implementation of any nonnative fish control activity will be the responsibility of appropriate management agencies.

Executive Summary

The Glen Canyon Dam Adaptive Management Program (GCDAMP) recommended that the U.S. Geological Survey's Grand Canyon Monitoring and Research Center develop a process, a

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schedule, and a recommended budget for suppression and control of non-native fish for the Colorado River in Grand Canyon. This document seeks to respond to that charge by describing a comprehensive approach for research, monitoring, and control actions related to nonnative fish species in the ecosystem. This document is consistent with GCDAMP goals to improve the status of native fish in Grand Canyon, especially the federally listed endangered humpback chub (*Gila cypha*), and to maintain a naturally reproducing population of rainbow trout (*Oncorhynchus mykiss*) above the Paria River to the extent practicable and consistent with the maintenance of viable populations of native fish.

The Colorado River and its tributaries in Grand Canyon are an interconnected system that includes a variety of fish habitats and species. As a result, the threats posed by nonnative fish to native species throughout the system are diverse and require a multifaceted management response. To develop an appropriate response, this ~~plan~~document summarizes the history of nonnative fish management efforts in Grand Canyon, including an overview of recent efforts to protect native species through nonnative control projects. A review of current nonnative fish monitoring and sampling efforts and nonnative fish captures in Grand Canyon are also included. Existing information and data provide the basis for the research, management, and monitoring strategies presented in this ~~plan~~document. Developing a complete spectrum of nonnative fish monitoring and control methods and a risk assessment will take additional time.

An examination of recent and current fish sampling efforts reveals the need to improve nonnative fish monitoring, address information gaps, and facilitate the ability of managers to share information about and to rapidly respond to emerging and urgent threats caused by nonnative fish. Suggestions for making strides in these areas are included here. A review of exiting information also indicates that the long-term control of nonnative fish populations in Grand Canyon may require the control of nonnative species in the broader watershed. For example, source populations of nonnative fish that impact Grand Canyon native fish may originate outside of Grand Canyon and may not fall within the scope of the GCDAMP.

This ~~plan~~document outlines a comprehensive approach that prioritizes nonnative fish monitoring, removal, and research strategies for Grand Canyon. Monitoring recommendations proposed by this ~~plan~~document and presented in the order of their importance are as follows:

1. Expansion and diversification of current mainstem monitoring methods
2. Development of an early detection mechanism for alerting managers to nonnative fish invasions in Lees Ferry and the Colorado River from tributary sources
3. Implementation of a long-term fish monitoring program for Grand Canyon tributary streams

Control options for nonnative fish proposed by this ~~plan~~document and presented in the order of their importance are as follows:

1. Maintenance of trout abundance in the Little Colorado River reach at 10 to 20 percent of January 2003 rainbow trout abundance (approximately 600 to 1,200 rainbow trout)
2. Continued removal of nonnative fish from tributaries including a) rainbow trout from Shinumo Creek in association with humpback chub translocation efforts using backpack electrofishing in combination with other methods, b) trout species from Bright Angel Creek using a weir and backpack electrofishing.
3. Removal of channel catfish (*Ictalurus punctatus*) and bullhead species in and around the Little Colorado River
4. Chemical renovation and barrier construction in tributary streams identified as sources of nonnative fish into Grand Canyon

Control options for future consideration include stocking daughterless common carp (*Cyprinun carpio*) and the introduction of infectious agents.

Research recommendations proposed by this ~~plan~~document and presented in the order of their importance are as follows:

1. Development of a bioenergetics, or ecosystem modeling, approach to identify nonnative species posing the greatest risk to natives
2. Identification of sources of juvenile and adult nonnative fish into the mainstem, including tributary inflows, dam passage, and stocking, and isotope and larval drift studies to identify spawning areas and natal origins of nonnative fish
3. Improvement of monitoring methods through use of a model or an alternative approach to track changes in abundance and distribution of nonnative fish
4. Implementation of small-bodied nonnative fish and young-of-year (YOY) capture and monitoring studies using slow-shocking techniques in the mainstem
5. Continued development of remote PIT-tag detection technology for use on nonnative fish and in tributary streams
6. Use of large-mesh gill nets to target common carp in the Little Colorado River and its confluence with the mainstem Colorado River
7. Development of targeted flow and temperature manipulations to disadvantage nonnative fish, including continuing efforts to install and operate a temperature control device on Glen Canyon Dam
8. Use of pheromone and sensory attractants to increase nonnative fish captures
9. Implementation of sonic telemetry studies for native and nonnative fish to compare and identify spatial and temporal movement patterns, tributary use, and spawning areas
10. Use of experimental stream tests to investigate mechanisms by which nonnative fish negatively affect juvenile humpback chub
11. Modification of Williams' Carp Cage for application to common carp control in tributary streams

Other activities that could improve the management of nonnative fish include the following measures, which are listed in the order of their importance:

1. Conduct an annual nonnative fish workshop with cooperators, managers, and other nonnative fish experts
2. Initiate a public outreach effort specifically dealing with nonnative fish management issues that emphasizes preventative measures such as deterring illegal stocking
3. Develop a formalized reporting procedure for nonnative fish captured and observed by those professional entities sampling aquatic environments within Grand Canyon

This ~~plan~~document suggests evaluating the use of triggers tied to changes in nonnative species catch rates, distribution, community composition, and length frequency to initiate control efforts. Triggers would be reviewed annually by scientists and managers.

The recommendations and options presented above attempt to balance the recommendations made for monitoring and research needs with the application of control options. However, research and monitoring improvement recommendations outnumber control options, a balance that accurately reflects the current state of knowledge regarding nonnative fish in Grand Canyon. Addressing expansion of nonnative fish species currently present or new to the system could be limited by the capture methods currently available for most species in Grand Canyon. This situation necessitates the use of sampling gears with moderate, poor, or unknown capture efficiencies while newer, more sustainable or effective methods are being evaluated. In the interim, combining several capture methods and focusing on problem areas with the gears that are most likely to capture target species offer the best opportunity to temporarily reduce nonnative species.

This document identifies the need for a contingency fund to support future pressing nonnative fish control needs and to avoid impacting ongoing monitoring and research activities. The costs of nonnative control efforts will vary depending on many factors, including target species, gear required, removal location, specific project goals, and other factors. Currently, based on the immigration rates observed from 2003 to 2006 and recent (2009) monitoring data, it is estimated that a minimum of two removal trips per year could be required (under a low immigration scenario of 50 fish per month) to maintain the population of 600 to 1,200 rainbow trout in the Little Colorado River reach (10 to 20 percent of the size of the January 2003 population). The cost of a single trip is $150,000, meaning that two control trips would cost approximately $300,000. This ~~plan~~document suggests that the GCDAMP contribute $300,000 annually to a nonnative fish control contingency fund, accumulating up to a maximum of $900,000 over 3 years. This fund would be available for controlling any nonnative species in Grand Canyon determined to be pose a high risk to humpback chub.

Implementation of the recommendations and options presented by this document and others brought forth during future nonnative fish workshops must involve scientists, resource managers, tribal members and other stakeholders. Several of the monitoring and research recommendations contained within this document will be implemented as part of the GCMRC work plan for fiscal years (FY) 2010–11. This document is intended to provide the technical foundation for management agencies with statutory authority to initiate the development of a comprehensive nonnative fish management plan for Grand Canyon. This document is not intended to obligate management agencies to implement any control option presented herein. Management agencies working through the AMP will evaluate nonnative fish control implementation based on scientific, policy, legal and financial considerations. Implementation of control options presented in this document will be carried out in compliance with management agency policies, mandates, and tribal consultation requirements. Necessary compliance for the implementation of any nonnative fish control activity will be the responsibility of appropriate management agencies.

This document provides examples of project prioritization processes and anticipates implementing one of these processes during the 2010 GCDAMP Nonnative Fish Workshop. This will assist scientists and managers in prioritizing research, monitoring recommendations and control options presented by this document and others brought forth. The need for management agencies to define their roles and responsibilities in nonnative fish management, identify and address institutional concerns regarding nonnative fish control implementation, and clearly define desired future conditions is also presented. This document provides an example of a rapid response plan to assist management agencies in identifying issues that impede the ability to move forward with the development and implementation of multi-agency rapid responses to newly invading nonnative fish species and the development of a comprehensive nonnative fish management plan for Grand Canyon.

Nonnative Fish in Grand Canyon – Summary of Nonnative Fish Control Options and Recommended Monitoring and Research Activities

Introduction and Purpose

Colorado River native fish evolved in extreme environmental conditions. Historically, native fish encountered annual water temperatures ranging from near freezing to more than 29°C (84°F) (Voichick and Wright, 2007), flows ranging from less than 85 cubic meters per second (m^3/s) up to 8,500 m^3/s (3,000 to 300,000 cubic feet per second), and turbidity ranging from clear water to flowing mud (Miller, 1961; Topping and others, 2003). Almost all physical and chemical conditions of the predam Colorado River fluctuated quickly and radically (Minckley, 1973). Colorado River Basin native ichthyofauna evolved under these harsh conditions into a relatively depauperate collection of only 36 species. Paleontological and archaeological records indicate only eight native fish species commonly occurred in the Colorado River through Grand Canyon, including the endangered humpback chub (*Gila cypha*) (Minckley and others, 1986; Minckley and Deacon, 1991). Most of the Grand Canyon native fishes are found nowhere else in the world.

Water development and nonnative species introductions have substantially changed natural ecosystem processes and are cited as primary factors contributing to the decline and even extinction of native fish (Miller, 1961; Minckley and Deacon, 1991; Lassuy, 1995; Tyus and Saunders, 2000; Mueller and Marsh, 2002), although, other factors have also contributed (Webb and others, 2004). Nonnative fish were introduced into the Colorado River before and after the completion of Glen Canyon Dam in 1963 (Woodbury, 1959; Valdez and Ryel, 1995). Between 1956 and 1996, 24 nonnative fish species were reported in Grand Canyon, and of these 17 were present before the closure of Glen Canyon Dam (Valdez and Ryel, 1995; Wieringa and Morton, 1996). Since 1996, researchers have captured approximately 13 nonnative fish species in Grand Canyon (Valdez and Ryel, 1995; Rogers and others, 2008; and Ackerman, 2007) (see appendix A for descriptions of some nonnative fish species found in Grand Canyon).

Managers and scientists have expressed concern about the impacts of nonnative fish on native fish in Grand Canyon. For example, nonnative fish may prey on and compete for food and habitat with various life stages of humpback chub as well as cause habitat degradation. The control of warmwater nonnative fish in Grand Canyon has become a growing concern because these species might benefit from warmer water releases from Glen Canyon Dam resulting from the possible construction of a temperature control device or climatic effects (Seager and others, 2007). Warmer water temperatures could increase the potential threat to Colorado River native species from nonnative fish adapted to warm water (Eaton and Scheller, 1996; Mueller and others, 1999; Garrett and others, 2003; Gloss and Coggins, 2005; Chu and others, 2005; Rahel and Olden, 2008; Valdez and Speas, 2009).

In light of growing concern, the U.S. Geological Survey's (USGS) Grand Canyon Monitoring and Research Center (GCMRC) was directed to develop a process, a schedule, and a recommended budget for suppression and control of non-native fish (warm water species) in Grand Canyon by the Glen Canyon Dam Adaptive Management Program (GCDAMP), a Federal initiative to maintain and protect resources downstream of Glen Canyon Dam. Development of a comprehensive nonnative fish management plan by appropriate management agencies will take time while additional nonnative fish monitoring and control strategies suitable for Grand Canyon are developed. This document is intended to articulate immediate needs and includes strategies for improving nonnative fish monitoring, preventing new nonnative fish species invasions, addressing information gaps, facilitating communication and rapid response to urgent nonnative fish issues, and defining near-term research needs.

Consistent with the strategic approach implemented by Tyus and Saunders (1996) in the upper basin of the Colorado River, participants in GCMRC nonnative fish workshops agreed that the primary goal of nonnative fish management efforts is to reduce negative impacts of nonnative fish on endangered humpback chub, especially juveniles in and around the confluence of the Colorado and Little Colorado Rivers. Efforts should be focused on the nonnative species that most threaten humpback chub and other natives in areas known to be of importance to native fish. Currently, nonnative rainbow trout (*Oncorhynchus mykiss*) are thought to pose the greatest risk to humpback chub (Yard and others, in prep.) and have been the primary, though not sole, target of nonnative control efforts to date. A risk assessment is needed to more rigorously test and confirm which nonnative fish species most threaten humpback chub and other natives. The GCMRC has made progress in this area and will continue to refine the risk assessment as part of its work plan for fiscal years (FY) 2010–11.

Clearly, once particular species are determined to pose a risk to humpback chub, greater control efforts can be directed at those species. The goal of implementing nonnative fish control is to apply an efficient removal technique in a localized area to target the particular species and life stages of nonnative fish found to be the greatest detriment to juvenile humpback chub. Other native fish currently found in Grand Canyon include speckled dace (*Rhinichthys osculus*), flannelmouth sucker (*Catostomus latipinnis*), and bluehead sucker (*Catostomus discobolus*). All native fish species are anticipated to benefit from nonnative fish control efforts, which would reduce predators and competitors.

This document begins with an overview of recent efforts to protect native fish through the control of nonnative fish species in Grand Canyon under the auspices of the GCDAMP. The document includes a review of nonnative fish captures in Grand Canyon, a review of ongoing and recent fish projects, and a discussion of a nonnative mechanical removal project conducted near the confluence of the Colorado and Little Colorado Rivers. Examination of recent and current fish sampling efforts reveals the need to improve monitoring of nonnative fish, close information gaps, and communicate and respond to urgent needs more rapidly. Based on these conclusions, this document presents (1) improvements in nonnative fish monitoring capabilities and methods for detecting the presence of new invasive species, (2) nonnative fish control options applicable to Grand Canyon, (3) research needs to advance the ability to control nonnative fish, (4) improvements in information sharing and communication among fisheries scientists and managers, (5) improvement of public outreach on the threats posed by nonnative species, (6) contingency planning needs, (7) examples of project prioritization processes, and (8) an example of a rapid response plan to assist management agencies in identifying issues that impede the ability to move forward with the development and implementation of multi-agency rapid responses to newly invading nonnative fish species and the development of a comprehensive nonnative fish management plan for Grand Canyon. An estimate of FY2010–11 costs associated with nonnative fish monitoring, research, and control activities are also presented

Background

Native Fish Protection and the Glen Canyon Dam Adaptive Management Program

The physical characteristics of the Colorado River in Grand Canyon are influenced by operation of Glen Canyon Dam. Growing public concern about dam-related impacts to the aquatic environment and other resources prompted Congress to pass and the President to sign into law the Grand Canyon Protection Act (GCPA) of 1992, which addresses the effects of dam operations on downstream resources in Glen Canyon National Recreation Area and Grand Canyon National Park (GCNP). In accordance with the Endangered Species Act, the 1996 Record of Decision implemented a modified version of the preferred alternative presented in the *Operation of Glen Canyon Dam Final Environmental Impact Statement* that would permit recovery and long-term sustainability of downstream resources while allowing flexibility in hydropower production. The GCDAMP is a process whereby "the effects of dam operations on downstream resources would be assessed and the results of those assessments would form the basis of future dam operations" (U.S. Department of the Interior, 1995, p. 34). The GCDAMP includes a Federal Advisory Committee, the Adaptive Management Work Group (AMWG), a Technical Work Group (TWG), independent scientific review panels, and the GCMRC, which has responsibility for scientific monitoring and research efforts for the program.

In 2001, members of the GCDAMP drafted a strategic plan outlining 12 goals and associated management objectives intended to guide downstream resource protection. One of those goals is to maintain or attain viable population of native fish (GCDAMP Goal 2), and this ~~plan~~document is a component of this broader goal. The GCDAMP recognized the negative impacts of nonnative fish on native fish and developed a list of information needs related to nonnative fish (Fairley and others, 2005). Further, in 2009, the GCDAMP developed a draft *Comprehensive Plan for the Management and Conservation of Humpback Chub in the Lower Colorado River Basin* (HBCCP) to provide a broad list of actions designed to better understand and ameliorate threats to the recovery of the humpback chub. Control and removal of nonnative fish was one of the primary actions recommended by the HBCCP. However, the GCDAMP explicitly recognizes the importance of maintaining the Lees Ferry rainbow trout fishery (GCDAMP Goal 4), a nonnative species, to the extent practicable and consistent with the maintenance of viable populations of native fish. As a result, this document seeks not only to protect native species, but also to be consistent with the GCDAMP goal of maintaining the Lees Ferry trout fishery.

Core monitoring information needs (CMIN), research information needs (RIN), and effects information needs (EIN) were developed by the GCDAMP to direct research and monitoring to specific resource protection issues. The GCMRC developed a crosswalk table showing how the approximately 250 information needs in the *GCDAMP Strategic Science Plan* related to the strategic science questions (SSQs) in the draft *Monitoring and Research Plan* (Grand Canyon Monitoring and Research Center, 2007a). The GCDAMP Science Advisors identified new SSQs relating to nonnative fish to be included in the monitoring and research plan. The GCDAMP goals, management objectives, strategic science questions, and information needs related to native fish conservation and nonnative fish control are presented below.

> **Goal 2**. Maintain or attain viable populations of existing native fish, remove jeopardy for humpback chub and razorback sucker, and prevent adverse modification to their critical habitats.

MO 2.4 Reduce native fish mortality due to nonnative fish predation/competition as a percentage of overall mortality in the Little Colorado River and mainstem to increase native fish recruitment.

New SSQ-A. What are the most effective strategies and control methods to limit nonnative fish predation on, and competition with, native fishes?

New SSQ-B. What life stage(s) of rainbow trout pose the greatest threat to humpback chub and other native fishes? Are the rainbow trout that threaten humpback chub resident fish produced in the Little Colorado River reach of the Colorado River, or are these rainbow trout immigrants that were spawned in the Lees Ferry reach?

SSQ 1-4. Can long-term decreases in abundance of rainbow trout in Marble and eastern Grand Canyons be sustained with a reduced level of effort of mechanical removal or will recolonization from tributaries and from downstream and upstream of the removal reach require that mechanical removal be an ongoing management action?

SSQ 1-7. Which tributary and mainstem habitats are most important to native fishes and how can these habitats best be made useable and maintained?

SSQ 5-6. Do the potential benefits of improved rearing habitat (warmer, more stable, more backwater and vegetated shorelines, more food) outweigh negative impacts due to increases in nonnative fish abundance?

CMIN 2.4.1 Determine and track the abundance and distribution of nonnative predatory fish species in the Colorado River ecosystem and their impacts on native fish.

RIN 2.4.1 What are the most effective strategies and control methods to limit nonnative fish predation and competition on native fish?

RIN 2.4.2 Determine if suppression of nonnative predators and competitors increases native fish populations.

RIN 2.4.3 To what degree, which species, and where in the system are exotic fish a detriment to the existence of native fish through predation or competition?

RIN 2.4.4 What are the target population levels, body size, and age structure for nonnative fish in the Colorado River ecosystem that limit their levels to those commensurate with the viability of native fish populations?

RIN 2.4.5 What are the sources (natal stream) of nonnative predators and competitors?

RIN 2.4.6 What are the population dynamics of those nonnative fish that are the major predators and competitors of native fish?

EIN 2.4.1 How does the abundance and distribution of nonnative predatory fish species and their impacts on native fish species in the Colorado River ecosystem change in response to an experiment performed under the Record of Decision, unanticipated event, or other management action?

Review of Fish Captures in Grand Canyon

Mainstem Colorado River in Grand Canyon

The mainstem of the Colorado River below Glen Canyon Dam is divided into fish sampling reaches (fig. 1 and table 1; Walters and Korman, 1999). From 2006 to 2008, the upper reaches of the river were dominated by coldwater nonnative species such as rainbow trout, and the lower reaches were dominated by warmwater species such as fathead minnow (*Pimephales promelas*), red shiner (*Cyprinella lutrensis*), common carp (*Cyprinus carpio*), and channel catfish (*Ictalurus punctatus*) (fig. 2). Brown trout (*Salmo trutta*) were captured in greatest numbers in reach 5 in proximity of Bright Angel Creek (Johnstone and Lauretta, 2007; Rogers and others, 2008). Red shiners, common carp, channel catfish, and striped bass (*Morone saxatilis*) were the dominant nonnative species in the mainstem below Diamond Creek downstream to the Lake Mead delta area (Ackerman, 2007; fig. 2). Other nonnative fish commonly captured in the mainstem of the Colorado River include bullhead species (*Ameiurus* spp.) near the Little Colorado River and plains killifish (*Fundulus zebrinus*) from the Little Colorado River downstream to Diamond Creek. Less commonly captured nonnative fish include threadfin shad (*Dorosoma petenense*), golden shiners (*Notemigonus crysoleucas*), Western mosquitofish (*Gambusia affinis*), green sunfish (*Lepomis cyanellus*), bluegill sunfish (*Lepomis macrochirus*), smallmouth bass (*Micropterus dolomieu*) and walleye (*Sander vitreus*; fig. 2).

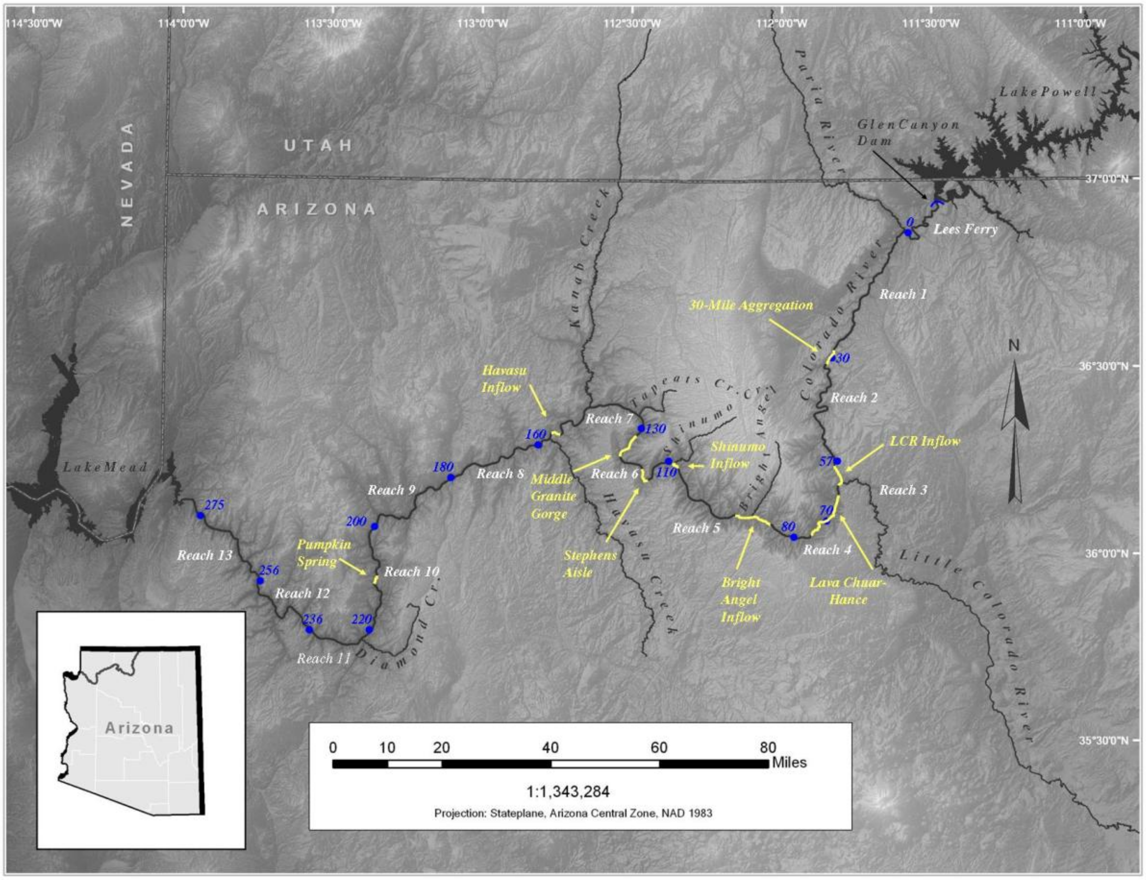
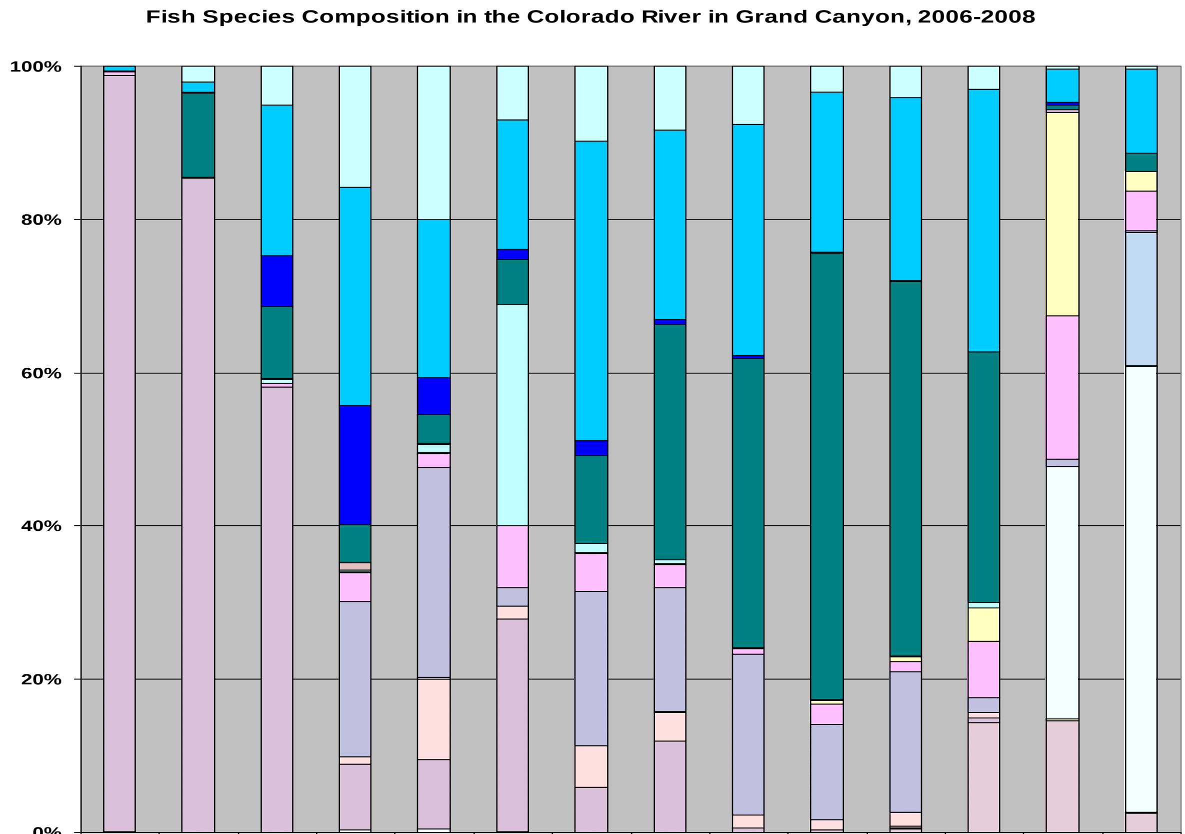


Figure 1. A map showing fish sampling reaches (Walters and Korman 1999) and the location of humpback chub aggregations (in yellow; Valdez and Ryel 1995) in the Colorado River below Glen Canyon Dam. See table 1 for specific river mile designations.

Table 1. Sampling reaches (Walters and Korman 1999) and location of humpback chub aggregations (Valdez and Ryel 1995) denoted by river mile designations in the Colorado River below Glen Canyon Dam and depicted in figure 1.

Sampling reach	River miles	Humpback chub aggregations	River miles
Lees Ferry	-16 - 0		
1	0 – 30.9	30-Mile	29.8 – 31.3
2	31.0 – 56.9		
3	57.0 – 69.9	Little Colorado River Inflow	57.0 – 65.4
4	70.0 – 79.9	Lava Chuar-Hance	65.7 – 76.3
5	80.0 – 109.9	Bright Angel Creek Inflow Shinumo Creek Inflow	83.8 – 92.2 108.1 – 108.6
6	110.0 – 129.9	Stephen Aisle Middle Granite Gorge	114.9 – 120.1 126.1 – 129.0
7	130.0 – 159.9	Havasu Creek Inflow	155.8 – 156.7
8	160.0 – 179.9		
9	180.0 – 199.9		
10	200.0 – 219.9	Pumpkin Spring	212.5 – 213.2
11	220.0 – 235.9		
12	236.0 – 255.9		
13	256.0 – 276.5		

Native fish captures in Grand Canyon include humpback chub, speckled dace, bluehead sucker, and flannelmouth sucker. Aggregations of humpback chub have been found to exist throughout the mainstem Colorado River in Grand Canyon (Valdez and Ryel 1995; fig. 1 and table 1). From 2006 to 2008, native species appeared to dominate the fish community in the mainstem in proximity of the Little Colorado River and from below Bright Angel Creek, river mile (RM) 109, to the last rapid near Bridge Canyon (RM 236). Nonnative species dominate the fish community from Glen Canyon Dam to the Little Colorado River (RM 57), in proximity of Bright Angel Creek, and in the lower reaches of the Colorado River below Bridge Canyon (RM 236; fig. 2).



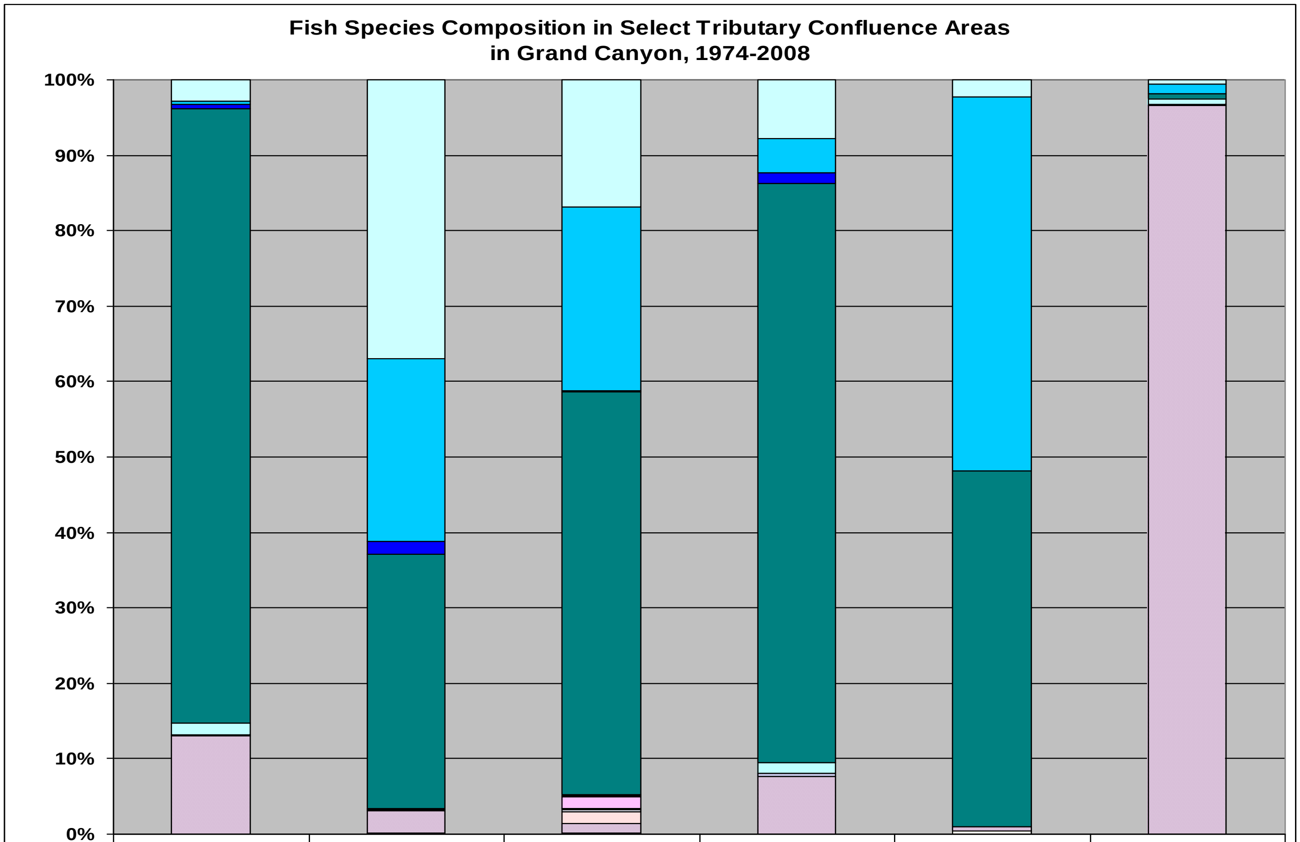
	Lees Ferry	RM 0-30	RM 31-56	RM 57-69	RM 70-79	RM 80-109	RM 110-129	RM 130-159	RM 160-179	RM 180-199	RM 200-219	RM 220-236	RM 237-256	RM 257-276
BHS	1	43	226	2325	168	71	202	170	419	103	125	9	1	5
FMS	34	26	883	4209	173	173	811	506	1670	628	717	103	14	136
HBC		4	298	2283	40	13	39	14	17	3	5		1	
SPD		225	422	734	31	60	236	629	2086	1756	1469	98	2	31
BBH			4	142	1					1	3			
BGS													1	
BNT	12	3	21	37	10	294	27	9	7	3	2	2		
CCF	1			15	1	1	1	3	1	12	16	13	84	32
CRP	27		22	552	15	82	103	62	43	81	42	22	59	65
FHM			3	2988	229	25	417	331	1162	373	550	6	3	2
GSF	1		1	1	2			1		1				1
MOS														217
PKF				137	88	17	112	78	93	39	55	2		1
RBT	6272	1762	2606	1272	76	283	123	243	31	11	9	2		
RSH				47	4	1		1			1		104	727
SMB				1									1	1
STB										1	16	43	46	32
WAL	5													

Figure 2. Fish captures in the mainstem Colorado River below Glen Canyon Dam using sampling reaches established by Walters and Korman, 1999. Species composition was determined by aggregating all 2006–08 mainstem fish captures recorded in the Grand Canyon Monitoring and Research Station fish database and dividing them into the designated river reaches. Native fish are represented by solid bars and nonnative fish are represented by hatched bars. The use of the river miles (RM) has a historical precedent and provides a reproducible method for describing locations along the Colorado River; Lees Ferry is the starting point, at RM 0, for mileage measured in both upstream and downstream directions. (See table 2 for key to species name abbreviations).

Colorado River Tributaries

Tributary streams have been identified as sources of native and nonnative fish entering the mainstem Colorado River (Stone and others, 2007). For example, relatively few warmwater nonnative species are captured in the mainstem upstream of its confluence with the Little Colorado River; however, nonnative fish such as young-of-year (YOY) common carp, red shiner, fathead minnow, channel catfish, bullhead spp., and plains killifish are captured in proximity to and downstream of the confluence of the Colorado and Little Colorado Rivers (Johnstone and Lauretta, 2007; Rogers and others, 2008). These species are regularly captured in the Little Colorado River (VanHaverbeke, 2006). Similarly, brown trout catch rates in the mainstem increase in the proximity of Bright Angel Creek (Rogers and others, 2008; Johnstone and Lauretta, 2007). The increases in nonnative fish captures in the proximity of these tributaries are likely the result of downstream dispersal of fish from tributaries into the mainstem (Leibfried and others, 2003). Alternatively, the capture of nonnative fish near tributaries may also be caused by staging of fish near the tributary to carry out some aspect of their life history such as spawning. The possibility that adults are staging near tributaries to spawn is evidenced by the capture of adult brown trout, which were initially tagged in the mainstem, in Bright Angel Creek in spawning condition (Leibfried and others, 2003). Humpback chub, fathead minnow, bluehead sucker, and channel catfish spawn in the Little Colorado River (Kaeding and Zimmerman, 1983; Maddux and others, 1987). Flannelmouth sucker spawn in the Paria River (Weiss, 1993; Thieme and others, 2001; Maddux and others, 1987) and rainbow trout in Nankoweap, Clear, Bright Angel, Crystal, Tapeats, Deer, and Shinumo Creeks (Maddux and others, 1987). Observation of YOY and spawning adult fish in these Colorado River tributaries highlights their potential importance as spawning areas, however, the importance of these tributaries for recruitment and persistence of native and nonnative fish in tributaries and the mainstem is not known.

Many of the tributary streams in Grand Canyon, with the exception of Tapeats Creek, contain a strong native and diverse nonnative fish community (fig. 3). Tapeats Creek is dominated by nonnative trout. Other nonnative fish species sporadically captured in tributaries of the Grand Canyon include common carp, red shiner, redside shiner (*Richardsonius balteatus*), fathead minnow, bullhead spp., channel catfish, brook trout (*Salvelinus fontinalis*), brown trout, rainbow trout, cutthroat trout (*Oncorhynchus clarki*), plains killifish, striped bass, green sunfish, and largemouth bass (*Micropterus salmoides*). The diversity of nonnative fish species captured in tributaries highlights the need to manage these potential sources of nonnative fish into the mainstem. This finding also suggests that tributaries must be managed to reduce the negative impacts of nonnative fish on native fish communities using tributary streams. The effectiveness of control techniques may be improved in tributary streams compared to the mainstem because of their smaller scale.



	Bright Angel	Havasu	Kanab	Shinumo	Paria	Tapeats
BHS	66	1475	1151	494	129	5
FMS	8	966	1657	287	2819	11
HBC	14	65	12	90		
SPD	1858	1342	3639	4898	2677	7
BNT	35	2	3	88		6
CCF	2	1	13	1		
CRP		6	107	2		
FHM			9	23		1
GSF			22			
GSH					5	
PKF		3	107	1		
RBT	298	118	84	487	31	867
RSH			3	1		
RSS					22	
STB		7	2			
YBH		1	3			

Figure 3. Fish captures in selected tributaries of the Grand Canyon contained within the Grand Canyon Monitoring and Research Center database. Captures represent fish species captured in the tributary and its confluence area with the mainstem Colorado River. Composition represents captures with all gear types from 1974 to 2008 because of the limited number of capture records in tributaries. Native fish are represented by solid bars and nonnative fish are represented by hatched bars. Translocation of humpback chub into Shinumo Creek occurred in 2009 and is not included in this figure. (See table 2 for key to species name abbreviations).

Review of Glen Canyon Dam Adaptive Management Program Efforts to Control Nonnative Fish in Grand Canyon

In 2002, the AMWG directed the TWG's Nonnative Fish Control Ad Hoc Committee to develop a plan for nonnative fish control in the Colorado River ecosystem for 2002 to 2006, with the expectation of improving conditions for the humpback chub and other native fish. The ad hoc committee developed the following eight recommendations (Persons and others, 2003):

- Improve public information and education efforts concerning nonnative fish impacts on native fish
- Evaluate methods to remove brown trout from Bright Angel Creek and consider the removal of rainbow trout after public input
- Evaluate shocking and removal of rainbow trout near the mouth of the Little Colorado River
- Evaluate common carp, channel catfish, and black bullhead removal using nets and other appropriate methods in the Little Colorado River
- Evaluate managed flows to disadvantage trout and other nonnative fish
- Evaluate the feasibility of a temperature control device to improve humpback chub and native fish recruitment
- Consider sediment augmentation or redistribution to benefit native fish
- Implement immediately any feasible control methods to address the urgent need to protect humpback chub

The HBCCP, dated February 2009, provides the following additional recommendations regarding nonnative fish:

- Control nonnative fish in Colorado River tributaries
- Control nonnative fish near the mouth and/or in the Lower 15 km of the Little Colorado River
- Develop a nonnative and invasive species control plan for Grand Canyon
- Develop procedures that govern when and where nonnative fish can be stocked in Grand Canyon

Since 2003, the majority of the recommendations made by the Nonnative Fish Control Ad Hoc Committee and the HBCCP have been implemented to one degree or another with funding from the GCDAMP, GCNP, and the Bureau of Reclamation. However, the continued development of methods to address nonnative fish species population expansion and to reduce negative effects on native fish owing to nonnative species is necessary to fully address the goals of the GCDAMP. The following is a list of planning activities and projects related to nonnative fish control conducted in Grand Canyon since 2002. Several of these methods are described in greater detail in the following section of this ~~plan~~document.

- Mechanical removal of nonnative fish with emphasis on rainbow trout near the Little Colorado River and associated public outreach efforts (See Coggins and others, 2007; Coggins, 2008)

- Trout removal in Bright Angel Creek and associated public outreach efforts (See Leibfried and others, 2003; SWCA Environmental Consultants, 2006; and Sponholtz and VanHaverbeke, 2007)
- Rainbow trout reduction and methods testing in Shinumo Creek associated with translocation of humpback chub (Grand Canyon National Park and SWCA Environmental Consultants, unpub. data.)
- Preliminary common carp, channel catfish, and bullhead reduction methods testing in the Little Colorado River (W. Persons, Arizona Game and Fish Department, oral commun., 2007)
- Flow management attempting to disadvantage rainbow trout recruitment in the Lees Ferry reach (Korman and others, 2005)
- Development of an assessment evaluating the benefits of a temperature control device on spawning, incubation and growth of native and nonnative fish (Valdez and Speas, 2009); the temperature control device was also evaluated by two review panels (Mueller and others,1999; Garrett and others, 2003)
- Investigation of new capture and monitoring methods for channel catfish in the mainstem Colorado River (Arizona Game and Fish Department and U.S. Geological Survey, unpub. data, 2007 and 2008)
- Feasibility testing of fish-tracking technology (Arizona Game and Fish Department and U.S. Geological Survey, unpub. data, 2007)
- Evaluation of the impact of a high flow event on rainbow trout movement in Lees Ferry (Hilwig and Makinster, in press)
- Development of a nonnative fish control plan for Grand Canyon

Review of Recent Fish Projects in Grand Canyon

Ongoing Mainstem Projects

Fish sampling methods currently used in the mainstem of the Colorado River in Grand Canyon have limitations in their ability to provide robust abundance measures for most warmwater nonnative fish. Table 2 summarizes recent fish sampling projects in the mainstem Colorado River. Each method is inherently biased for certain species, size classes, and habitat types, so multiple gears are used to monitor and sample fish in the mainstem. The following is a brief review of the applications and limitations of current fish sampling methods in developing nonnative fish planning approaches. A summary of these applications and limitations is given for both mainstem and tributary sampling.

Table 2. Description of ongoing mainstem fish projects in the Colorado River as of November 2009. Key below the table includes species codes, common names, and scientific names.

Monitoring event	Cooperator	Sample timing	Gear type	Sample description
Mainstem electrofishing	Arizona Game and Fish Department (AZGFD)	Twice/yr	Shoreline electrofishing	About 400 samples of about 300 seconds each
Lees Ferry monitoring	AZGFD	Three times/yr; spring, summer, winter	Shoreline electrofishing	Nine fixed sites, 27 random sites, 300 seconds per sample
Lees Ferry juvenile trout research	Ecometric, Inc. to be incorporated into AZGFD Lees Ferry Monitoring in 2010	Near-monthly sampling (sampling reduced in 2010)	Boat electrofishing, slow shocking, backpack shocking, 30 to 50 m sites	Evaluation of experimental flows on rainbow trout production and survivorship
Mechanical removal	AZGFD	Periodic; up to six times/yr	Boat electrofishing, hoop nets	Serial depletion electrofishing samples to remove trout in proximity of the Little Colorado River, hoop net samples to monitor native fish response
Nearshore ecology research	University of Florida	Four times/year, July–Oct.	Slow shocking, hoop nets, seines, minnow traps	Assessment of juvenile humpback chub shoreline habitat use associated with summer and fall flow fluctuations

Key to species codes, common names, and scientific names.

Code	Common name	Scientific name
	Native Fish	
BHS	Bluehead sucker	*Catostomus discobolus*
FMS	Flannelmouth sucker	*Catostomus latipinnis*
HBC	Humpback chub	*Gila cypha*
SPD	Speckled dace	*Rhinichthys osculus*
	Nonnative Fish	
BBH	Black bullhead	*Ameiurus melas*
BGS	Bluegill sunfish	*Lepomis macrochirus*
BNT	Brown trout	*Salmo trutta*
CCF	Channel catfish	*Ictalurus punctatus*
CRP	Common carp	*Cyprinus carpio*
FHM	Fathead minnow	*Pimephales promelas*
GSF	Green sunfish	*Lepomis cyanellus*
GSH	Golden shiner	*Notemigonus crysoleucas*
MOS	Western mosquitofish	*Gambusia affinis*
PKF	Plains killifish	*Fundulus zebrinus*
RBT	Rainbow trout	*Oncorhynchus mykiss*
RSH	Red shiner	*Cyprinella lutrensis*
RSS	Redside shiner	*Richardsonius balteatus*
SMB	Smallmouth bass	*Micropterus dolomieui*
STB	Striped bass	*Morone saxatilis*
WAL	Walleye	*Sander vitreus*
YBH	Yellow bullhead	*Ameiurus natalis*

Two parameters can be used to evaluate the effectiveness of nonnative fish monitoring efforts and gears as removal methodologies: the coefficient of variation (CV) and the capture probability. The CV is used to measure the ability of monitoring protocols in Grand Canyon to detect change in relative abundance over time. A CV value of 0.10 indicates a 90 percent chance of detecting a 13 percent change in relative abundance per 1-year time step and a 53 percent change during 5 years based on a two-tailed significance test with a linear relationship (Gerrodette, 1987). A CV value greater than 0.10 indicates a reduced power to detect change in catch rates over time. Analysis of CV is specific to species and gear type and can assist in evaluating the level of uncertainty in monitoring data. Capture probability is an estimate of the proportion of a population captured for a particular species, gear, and method. In the context of this document, capture probability provides a measure of the potential effectiveness of a particular sampling gear in capturing a particular species of fish.

Mainstem Electrofishing

The Arizona Game and Fish Department in cooperation with the GCMRC conducts mainstem monitoring twice a year using boat-mounted electrofishing. A variable length of shoreline is shocked for 300 seconds with approximately 15 amperes and 350 volts with two people netting fish (This mainstem electrofishing monitoring protocol is different from the slow shocking technique described for Lees Ferry monitoring.). Electrofishing conducted in the mainstem from below Lees Ferry to Diamond Creek from 2000 to 2003 was sampled with the intensity believed to be necessary for long-term monitoring (800 samples) to detect changes in catch rates of rainbow trout, brown trout, common carp, and some natives in Grand Canyon (5 year time series; Rogers and Makinster, 2006). Coefficients of variation (800 samples) for rainbow trout, brown trout, and possibly common carp from 2000 to 2003 data were 0.09, 0.10, and 0.09, respectively. Detectable increases in catch-per-unit effort (CPUE) over 5 years based on 80 percent confidence intervals were estimated to be 23 percent for common carp and 23 percent for rainbow trout. Estimated detectable decreases in CPUE were 19 percent for common carp, 19 percent for rainbow trout, and 21 percent for brown trout (Rogers and Makinster, 2006). However, the increased sampling that took place in reach 5 (Bright Angel Creek inflow reach; 197 samples) and reach 3 (Little Colorado River reach; 147 samples) in 2002 and 2003 highlight the effort necessary to detect localized annual trends (Rogers and Makinster, 2006). The current mainstem electrofishing monitoring protocol can detect large changes (>21 percent) over a 5-year time scale or larger changes in catch rates (that is, >100 percent change) over an annual time scale. Electrofishing conducted during mainstem monitoring may also be adequate in detecting the presence of strong cohorts of juvenile salmonids (Rogers and others, 2003; Makinster and others, 2008; Makinster and others, 2009).

Electrofishing conducted as part of the long-term fish monitoring program is effective at monitoring trends in rainbow trout, brown trout, and potentially common carp, as well as some natives (Makinster and others, 2009). Other nonnative fish species such as channel catfish, bullheads, striped bass, and small-bodied fish are not effectively monitored using this protocol (for example, other species are not readily captured by this gear and so only very large changes in the abundance of these species will be detected over periods of one or a few years). Development of consistent monitoring protocols to assess the expansion in abundance or distribution of these nonnative fish species is necessary to determine threats, evaluate triggers for implementation of control programs, and provide a baseline to measure the effectiveness of control efforts once they are implemented.

Based on monitoring data, electrofishing can also be evaluated for use as a potential reduction method. Repeated sampling using methods with relatively high capture probabilities (approaching 15 to 20 percent) for a particular species are preferred for nonnative fish removal programs because they are more efficient in reducing target species in Grand Canyon (Coggins, 2008). Estimated electrofishing capture probabilities, using the method discussed above in the mainstem, for rainbow trout and brown trout are 15 and 9 percent, respectively (Rogers and Makinster, 2006). Thus, one electrofishing sample could remove an estimated 15 percent of the rainbow trout and 9 percent of the brown trout population within the sample location. Electrofishing appears to be a viable reduction method for rainbow trout, at least over limited reaches for short time periods (Coggins, 2008), where removal of this species is desirable; however, the effectiveness of using electrofishing for reducing brown trout is less when compared to rainbow trout. Capture probability for common carp has not been determined for electrofishing but is assumed to be very low, thus, electrofishing is likely not a feasible technique to reduce common carp populations in Grand Canyon (R. Rogers, Arizona Game and Fish Department, pers. commun., 2008). The use of electrofishing should be carefully considered because it is only effective for certain species in specific conditions.

Mainstem electrofishing has limitations in population monitoring and reduction applications for most nonnative fish. Capture probabilities using electrofishing for smallmouth bass and walleye, which likely occur in very low densities in the Colorado River, are not known in the mainstem and Lees Ferry. The mainstem electrofishing monitoring protocol is not effective for monitoring or population reduction efforts for channel catfish, bullhead species, and small-bodied or young fish; this method results in very few captures of these species in locations where they are captured in greater numbers with other gears (Ackerman, 2007; Rogers and Makinster, 2006).

Lees Ferry

The Arizona Game and Fish Department, in cooperation with the GCMRC, conducts annual Lees Ferry monitoring using electrofishing. This effort targets rainbow trout using an electrofishing technique similar to the one used in the mainstem below Lees Ferry. This technique has also captured other species such as adult smallmouth bass and walleye (Makinster and others, 2007). Current mainstem and Lees Ferry electrofishing programs may be adequate for detecting the presence of adult smallmouth bass and walleye, however, the efficiency of electrofishing in capturing and removing these species, which occur in low densities, is not known.

Ecometric, Inc., in cooperation with the GCMRC, has sampled Lees Ferry using the "slow shocking" technique described by Korman and others (2006) that targets young rainbow trout as small as 30 mm. This sampling technique uses backpack shockers in short river sections in a variety of shallow habitats and shocking that is conducted with a boat electrofishing unit to sample areas where it is infeasible to sample with a backpack shocker. A 50 m length of shoreline is shocked for 500 seconds with 16–18 amperes and 200 volts. This method has captured several small nonnative fish on rare occasions in the Lees Ferry reach that may have otherwise been undetected, including YOY channel catfish, smallmouth bass, and green sunfish (Korman, unpub. data, 2007). This method will be incorporated into the Lees Ferry monitoring program in 2010.

Lees Ferry is an area where new nonnative species introductions are most likely to occur. Nonnative introductions result from unintentional or illegal stocking, movement of nonnative fish from Lake Powell through Glen Canyon Dam, dispersion from the large warm slough located near RM 12, and from the Paria River drainage into the mainstem. The introduction of new fish species into Lees Ferry is a concern because nonnative species that are introduced or become established in this reach can then disperse throughout the entire river system below Glen Canyon Dam. Although standard Lees Ferry monitoring protocols may be adequate for detecting adult smallmouth bass and walleye, there is not a rigorous monitoring protocol in place to detect invading nonnative fish in Lees Ferry or Grand Canyon.

Mechanical Removal

At the direction of the GCDAMP, a nonnative fish control program was implemented near the confluence of the Colorado and Little Colorado Rivers in January 2003 as part of a joint Federal action. The objective of mechanical removal is to reduce the number of all nonnative predatory and competitive fish in habitat occupied by native fish. This action was initiated on an experimental basis because it was thought possible that rainbow trout could be effectively captured with available electrofishing techniques and presented low risk relative to other actions intended to benefit native fish such as a selective withdrawal structure or modifications to flow regimes. The Arizona Game and Fish Department, in cooperation with the GCMRC, conducted mainstem mechanical removal in proximity of the Little Colorado River from 2003 to 2006 and in 2009 to reduce the abundance of rainbow trout primarily. From 2003 to 2006, six trips of four passes each were conducted each year, except in 2006 when only five trips were conducted. One trip was conducted in 2009.

YOY and juvenile native fish, including humpback chub, enter the mainstem Colorado River primarily from the Little Colorado River during freshet events (Valdez and Ryel, 1995). It is generally agreed that these young fish encounter a number of challenges affecting their survival, including suboptimal water temperatures, predatory and competitive nonnative fish (Yard and others, in prep.), and unstable shoreline habitat (Petersen and Paukert, 2005; Stone and Gorman, 2006; Paukert and Petersen, 2007). The primary removal reach (Little Colorado River removal reach) spanned river miles 56.2 to 65.7 of the Colorado River, which included the confluence with the Little Colorado River. In August 2003, an additional removal reach, Lava Chuar to Tanner, river miles 65.7 to 68.5, was also added. Nonnative fish were removed during 23 trips from January 2003 to August 2006. Nonnative fish were removed using electrofishing during 2 to 6 serial depletion passes (typically 4) within both removal reaches. These data were subsequently used to infer species composition and abundance trends within the removal reaches (Coggins and others, 2007; Coggins, 2008).

Results of mechanical removal suggest that serial depletion using electrofishing is an effective capture method for rainbow trout. Observed capture probabilities for rainbow trout ranged between 2 percent and 35 percent per pass, depending on location and time of year, but generally were >10 percent. Over the course of the experiment, rainbow trout abundance gradually reduced to approximately 10 percent of the January 2003 estimate, however, this reduction may have also been a result of other confounding factors discussed below. Additionally, overall community composition (by mass), as indexed by fish captured, was reduced from >90 percent nonnative fish to <40 percent (Coggins and others, 2007; Coggins, 2008). The impact of mechanical removal on other nonnative fish species such as common carp, fathead minnow, channel catfish, and bullheads is not clear.

It is possible that nonnative fish abundance, particularly of rainbow trout, was also reduced by factors other than mechanical removal. From 2003 to 2006, and particularly in 2005, water temperatures in the mainstem Colorado River were elevated by as much as 6°C relative to much of the postdam period (fig. 4). These temperatures possibly inhibited growth and survival of rainbow trout (Paukert and Petersen, 2007). Additionally, a downward trend in rainbow trout abundance was observed in both Lees Ferry and Marble Canyon beginning as early as 2002 (fig. 5). Finally, the immigration rate into the removal reaches generally decreased throughout the experiment, suggesting that the upstream source of rainbow trout may have declined in abundance.

In 2009, mechanical removal was reinitiated following a protocol similar to the one described above. Results from this removal effort should assist scientists in further evaluating the effectiveness of the effort. As results become available, this information should be incorporated into nonnative fish control planning approaches. As requested by the GCDAMP, the GCMRC has included this project in the work plans for FY 2010 and 2011.

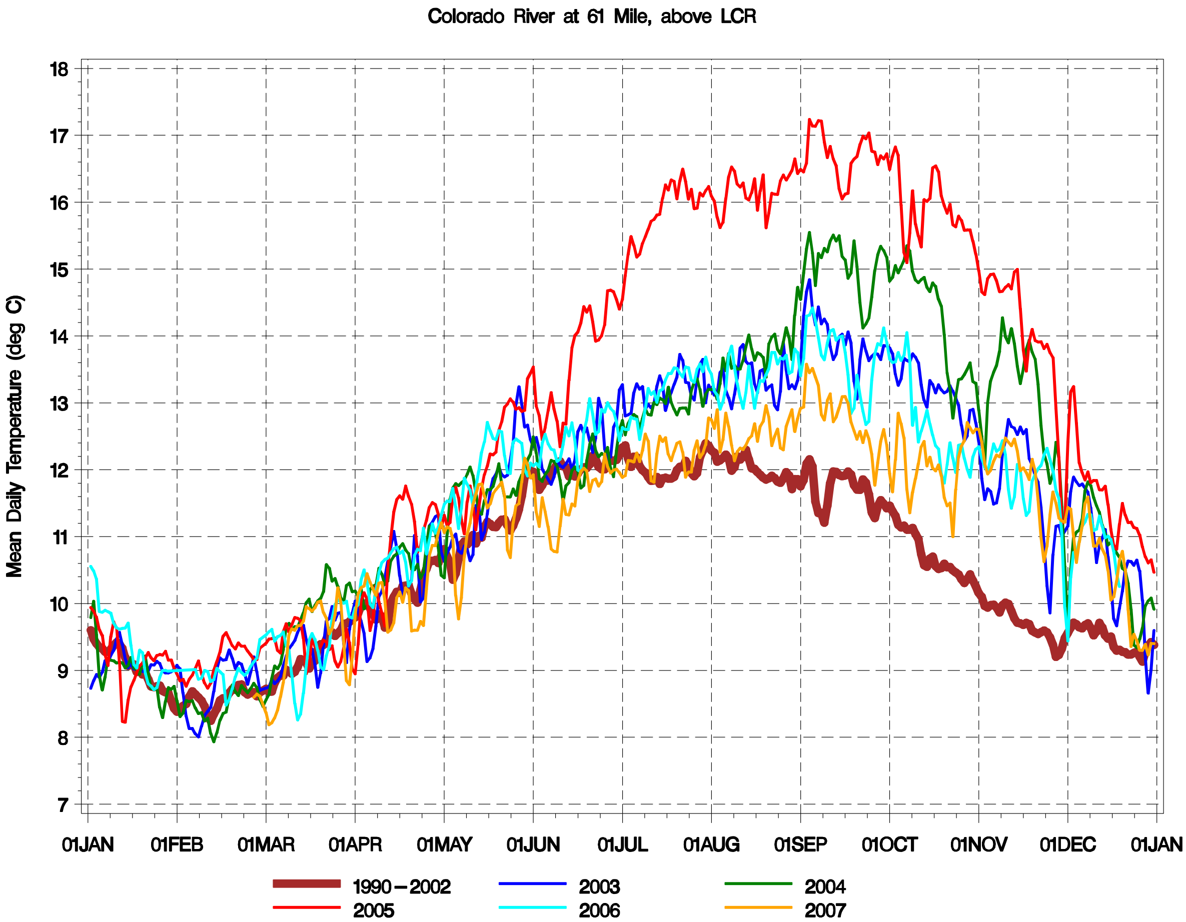


Figure 4. Mean mainstem water temperature measured at river mile 61 near the Little Colorado River confluence with the Colorado River from 1990 to September 2007. Bold red line indicates average daily release temperatures from 1990 to 2002.

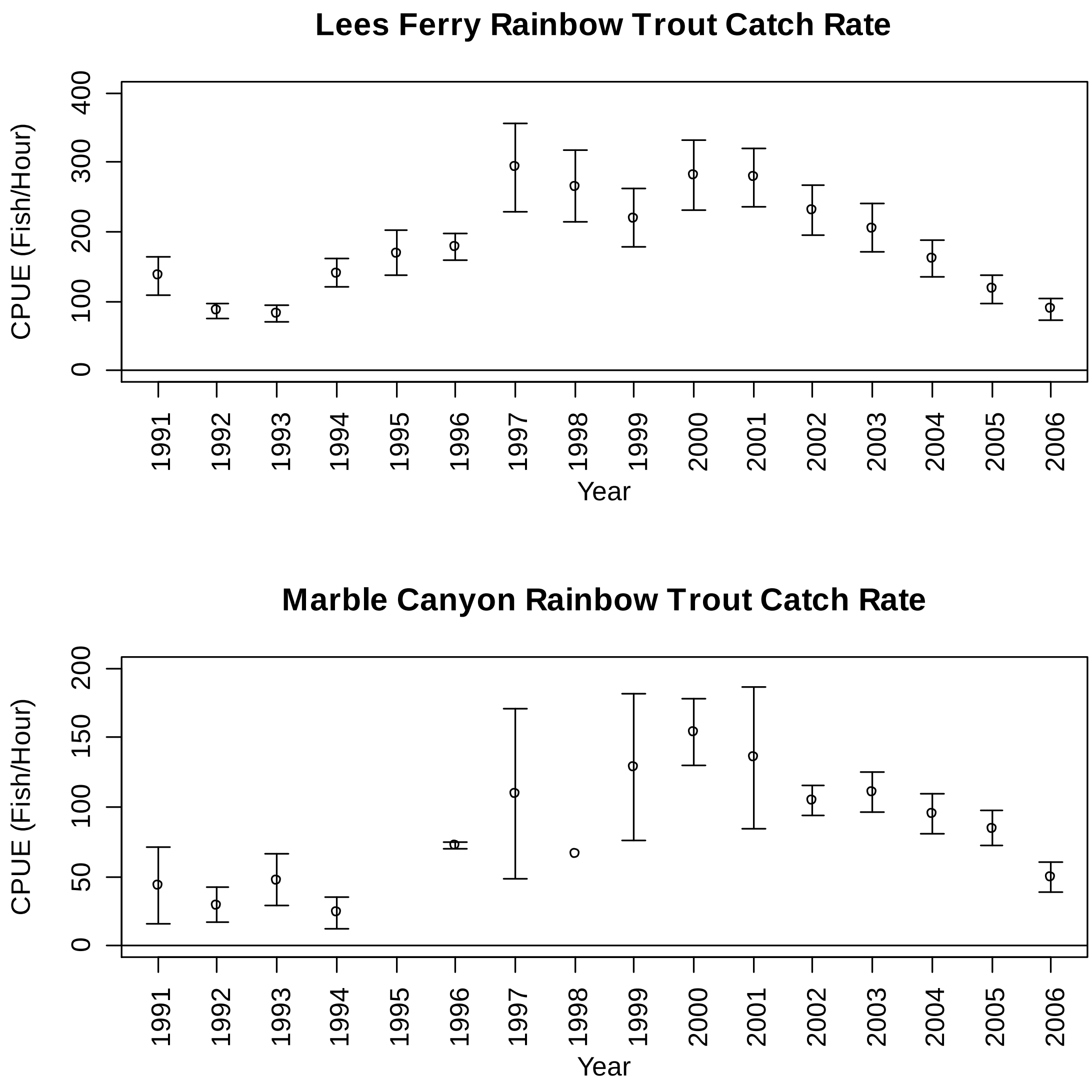


Figure 5. Relative abundance of rainbow trout indexed by electrofishing catch rate in the Lees Ferry reach (top) and in Marble Canyon (bottom; Lees Ferry to the Little Colorado River confluence). Estimates provided by the Arizona Game and Fish Department.

Nearshore Ecology

In 2009, University of Florida, Ecometric, and the State University of New York, in cooperation with GCMRC, initiated a 4-year research project to quantify abundance, survival, habitat use, growth, and natal source of juvenile humpback chub over three flow periods: (1) summer modified low fluctuating flows, (2) modified low fluctuating flow transition to fall steady experimental flows, and (3) fall steady experimental flows. Sampling trips were conducted in July, August, September, and October of 2009. This study will continue through 2011, and laboratory work and analysis will conclude in 2012. This effort employs the slow shocking technique in discrete mainstem habitat types around the confluence of the Little Colorado River to help understand the relative importance of these habitats and the impact various flow regimes have on their use by fish. This technique will allow for direct comparisons of backwater habitats with other nearshore areas such as talus slopes and cliff walls because the same sampling method will be used for all habitats. The nearshore ecology study targets humpback chub; however, based on the 2008 pilot studies conducted by the GCMRC, information on fathead minnow abundance and habitat use in the study area may be periodically obtained (M. Yard, U.S. Geological Survey, oral commun., 2009). This project may provide insight on (1) habitat overlap and potential competition juvenile humpback chub may incur from fathead minnows, (2) development of effective systemwide nonnative fish monitoring protocols, and (3) natal source studies that support the development of nonnative fish control methods. As results become available this information should be incorporated into nonnative fish planning approaches.

Ongoing Tributary Projects

There are currently no fish monitoring programs in place for Colorado River tributaries in Grand Canyon, with the exception of the Little Colorado River. Nonnative fish have been captured in the majority of tributary streams in Grand Canyon, representing a potential source of nonnative fish into the Colorado River. Sampling in tributaries beyond the immediate Little Colorado River confluence area has been sporadic and conducted by multiple organizations with multiple gears and sampling protocols. Unlike mainstem fish collection data, data associated with these sampling events are not maintained in a centralized database. In the mid 1980s, Maddux and others (1987) sampled extensively in several tributary confluence areas, and in the early 1990s, graduate students from the University of Arizona sampled in select tributaries of the Grand Canyon (Allen, 1993; Weiss, 1993). Following the mid 1990s, nonnative fish sampling in Grand Canyon tributaries did not occur until 2004 and 2005 (National Park Service, unpub. data). No other extensive sampling in tributary streams has occurred since 2005, with the exception of sampling conducted in Shinumo Creek to prepare for the translocation of humpback chub in 2009 (National Park Service, unpub. data).

Little Colorado River

The U.S. Fish and Wildlife Service and the Arizona Game and Fish Department, in cooperation with the GCMRC, conduct annual fisheries monitoring in the Little Colorado River from river kilometer (rkm) 13.6 downstream to the confluence with the Colorado River. Table 3 provides a summary of current monitoring activities in the Little Colorado River. The Little Colorado River is sampled with hoop nets primarily in the spring and fall. In addition, two monitoring trips are conducted above Chute Falls (rkm 18.1) periodically in the summer to evaluate humpback chub translocated above Chute Falls.

Monitoring in the Little Colorado River targets humpback chub but also results in the capture of nonnative species, though, they represented only 6 percent of the fish captured in hoop nets in the lower reaches of the river in 2008 (Stone, 2008). Monitoring trends in nonnative fish abundance using relative abundance measures is problematic because of the small numbers of nonnatives captured. However, YOY and juvenile channel catfish and bullhead species captures in the hoopnet samples were higher in 2008 than in previous years, indicating a successful recruitment year for these species in the Little Colorado River (Stone, 2008). Adult channel catfish and common carp were captured using angling in close proximity to hoop net sets in the lower most reach of the Little Colorado River (W. Persons, Arizona Game and Fish Department, oral commun., 2007), however, adult fish are rarely captured in hoop nets (Clark, 2008). Because of the low number of captures of nonnative fish in hoopnets in the Little Colorado River, reliable capture probability estimates are not available.

Currently, there is not a protocol to monitor changes in nonnative fish abundance in the Little Colorado River. Hoop nets capture YOY and juvenile channel catfish and common carp, indicating their effectiveness in at least detecting this age group; however, the effectiveness of this technique in reducing nonnative fish abundance is not known. Angling, effective in capturing adult channel catfish and common carp, also captures humpback chub and poses a mortality risk. Hoop netting and angling data for nonnative fish captures may be applied to the development of an occupancy model (see Occupancy Modeling section below) to better understand changes in nonnative fish abundance and distribution.

Table 3. Description of ongoing fish-monitoring activities in the Little Colorado River through November 2009.

Monitoring event	Cooperator	Sample timing	Gear type	Sample description
Lower 1,200 m of Little Colorado River monitoring	Arizona Game and Fish Department	Once/yr for 30-days in spring	1-m-diam, 5.0-m-length, 6.3-mm-mesh unbaited hoop nets with seven hoops and two throats	13 nets fished in standardized locations in the lower 1,200-m reach
Little Colorado River monitoring	U.S. Fish and Wildlife Service	Four times/yr for 10 days; twice in spring, twice in fall	0.6-m-diam, 1.0-m length, 6-mm-mesh unbaited hoop nets with three hoops and a single throat	About 540 hoop net nights, samples from rkm 13.57 to confluence
Chute Falls monitoring	U.S. Fish and Wildlife Service	Twice/yr for 5 days; summer	0.6-m-diam, 1.0-m-length, 6-mm-mesh baited hoop nets with a single 0.1-m throat	About 150 hoop net nights, samples from 18.1 rkm to 13.57

Other Recent Fish Related Projects in Grand Canyon

Modeling of Fish in Grand Canyon

Temperature Control Assessment

By assessing the predicted suitability of various temperature scenarios for spawning, incubation, and growth of fish in Grand Canyon, Valdez and Speas (2009) evaluated the potential impact of a selective withdrawal structure. This assessment considered the temperature suitability of four regions of the Colorado River in Grand Canyon for fish using predicted temperatures from the Bureau of Reclamation’s GEMSS® model. Three temperature scenarios evaluated were (1) no action, which provided maximum predicted release temperature of approximately 16ºC in November; (2) two units, which provided maximum predicted release temperature of 21ºC in June; and (3) four units, which provided maximum predicted release temperature of 24ºC in late July. Benefit is depicted as an increase in the number of river regions exhibiting suitable temperatures for a particular species to spawn, incubate, and grow based on an extensive review of such parameters by Valdez (2008). The results indicate that native fish gain the greatest benefit from a four unit structure in all river regions, however, seven of ten warmwater and four out of five coldwater nonnative species investigated also benefit from the warmer temperatures (See figs. 11 and C-1 in Valdez and Speas, 2009). Native fish would benefit from a two unit structure in many fewer regions of the river than with four units. Temperatures were predicted to be suitable for seven out of ten warmwater and five out of five coldwater nonnative fish with the two-unit scenario. When considering warmwater species alone, Valdez and Speas (2009) predict that warming mainstem temperatures could increase the temperature suitability of the mainstem for spawning, incubation, and growth of warmwater nonnative species.

The work of Valdez and Speas (2009) could be misinterpreted as predicting distributional changes of fish species in the mainstem. For example, this analysis predicts that under the no action scenario (similar to 2005 temperatures), no region of the river has suitable temperatures for spawning or growth of channel catfish (See fig. 11 in Valdez and Speas, 2009), which could be interpreted as depicting predicted channel catfish distribution in the Grand Canyon. However, channel catfish currently occur in proximity to the Little Colorado River and below Lava Falls. This example emphasizes that Valdez and Speas (2009) predict the impact of temperature control on the temperature suitability for various species to spawn, incubate, and grow rather than predicting species distribution. The predictions made by Valdez and Speas (2009) regarding the impact of warmer water releases on warmwater species are very conservative because only mainstem effects are considered. The authors emphasize this concept by stating that warming mainstem temperatures could allow for greater dispersal of species that are restricted to warmer tributary streams and other habitats by surrounding cold mainstem temperatures (Valdez and Speas, 2009).

The GCMRC attempted to interpret the no action scenario in the Valdez and Speas (2009) assessment to evaluate risk of nonnative species in Grand Canyon. The no action alternative was not specifically parameterized to emulate water temperature conditions in 2005, however, this scenario best approximates mainstem conditions that are most likely to occur in the near future. The following excerpt from Valdez and Speas (2009) summarized model results of the suitability of mainstem temperatures to spawning, incubation, and growth of nonnative species under the no action scenario:

> "… under No Action, the mainstem Colorado River through Grand Canyon was suitable only for rainbow trout and brown trout from the dam to the LCR. Downstream of the LCR, predicted temperatures remained cool and were suitable for rainbow trout, brown trout, walleye, redside shiner, and smallmouth bass."

From this one can infer that there is risk of these nonnative fish species encountering suitable conditions for spawning, incubation, growth, and persistence in the mainstem Colorado River through Grand Canyon. The risks for nonnative fish persistence in temperature conditions likely to occur in the near future are as follows: (1) brown and rainbow trout could persist throughout the river and (2) smallmouth bass, walleye, and redside shiner could persist downstream of the Little Colorado River to Lake Mead. To specifically evaluate the risks each of these species and others pose to juvenile humpback chub, information such as diet composition and habitat overlap should be incorporated into an ecosystem or bioenergetics model.

Threats to Juvenile Humpback Chub

The GCMRC is in the initial phases of developing an ecosystem model to evaluate factors that may negatively impact juvenile humpback chub in Grand Canyon. Recruitment failure has been identified as a limiting factor in maintaining adult humpback chub populations in Grand Canyon. Scientists have identified juvenile humpback chub recruitment in proximity of the Little Colorado River as the primary response variable in the model construction. Factors included in modeling efforts affecting humpback chub recruitment include food limitation, predation or competition, and temperature effects. Once models are constructed that reasonably emulate past conditions and fish population responses in Grand Canyon, simulations using other variables such as nonnative fish invasions or temperature variation will be evaluated. GCMRC scientists have been constructing datasets and identifying information needs for the development of these models.

Mainstem Hoop and Trammel Netting

In the past, SWCA Environmental Consultants, in cooperation with the GCMRC, conducted the mainstem Colorado River netting program designed to monitor native fish in Grand Canyon. Nonnative fish were captured sporadically using hoop and trammel nets. In 2006, the number of individual nonnative species captured in 1,044 hoop net samples and 293 trammel net samples combined was 40 common carp, 1 red shiner, 164 fathead minnows, 5 bullhead species, and 6 brown trout (Ackerman, 2007). Despite large fathead minnow captures relative to other species captured in hoop nets, the overall CV for this method and species approaches 0.70 (Johnstone and Lauretta, 2007). Capture probabilities for these gears have not been determined because of sporadic and sparse captures of nonnative fish. Hoop nets have provided valuable catch data for juvenile humpback chub but do not seem to be effective at monitoring or reducing populations of other species, although, other species may be rare in the reaches sampled. Because anecdotal observations suggested that trammel nets may cause unacceptable stress to native fish, especially humpback chub, the GCMRC suspended use of this gear in 2007 and supported a laboratory study of the impact of the gear on fish. Hunt (2008) found that in controlled settings fish captured in trammel nets had elevated levels of cortisol, especially at warmer water temperatures, suggesting that these fish had elevated stress levels compared to those not captured. This effect was less measureable at colder temperatures. Fish in these experiments experienced widespread mortality, but those fish subjected to warmest water expired most quickly. Because trammel nets have been effective for monitoring humpback chub in previous studies (for example, Valdez and Ryel, 2005), the 2009 Protocol Evaluation Panel for Grand Canyon Fishes recommended reinitiating use of this gear when water temperatures are less than 20°C. Hoop nets are periodically used to sample humpback chub aggregations, although, this technique has no demonstrated value in monitoring nonnative fish. These methods will be included in mainstem monitoring trips scheduled for 2010 and 2011.

Seining

In the past, SWCA Environmental Consultants and the U.S. Fish and Wildlife Service, in cooperation with GCMRC, conducted annual mainstem backwater seining sampling. The use of seines to monitor small-bodied and YOY nonnative fish is limited to backwaters, which represent only a very small portion of nearshore fish habitats found in the Colorado River, particularly in Grand Canyon (M. Breedlove, Utah State University, oral commun., 2007). Seining allows scientists to detect the presence of various species in backwaters; however, it is not possible to determine the relative importance of backwater habitats to small-bodied fish because only very limited assessments of their use of habitats other than backwaters has been attempted in Grand Canyon (Converse and others, 1998). The availability of backwater habitats also changes over time because of the transitory nature of sandbars that control some of these habitats and because different flows through Glen Canyon Dam alter the river stage, often over the course of one day, changing the inundation of backwaters.

Generally, when seining backwaters one seining pass is made through the backwater and captures of fish are recorded per area seined. Serial depletion samples have recently been added to the seining protocol to better track abundance and capture probability (Ackerman, 2007). Protocols have varied over the duration of the project. Nonnative species captured during seining include common carp, red shiner, fathead minnow, rainbow trout, plains killifish, and green sunfish. Seining CV for fathead minnow in backwater habitats is 0.14 and exceeds 0.25 for all other nonnative species (Ackerman, 2007). Capture probabilities using serial depletion seining samples in backwaters for fathead minnow ranged from approximately 65 to 90 percent and from 45 to 100 percent for plains killifish. Factors such as application of varying protocols over time, differences in backwater size, proportion of backwater area seined, and unequal capture probabilities among seine hauls and years confounds interpretation of trends in catch rate (U.S. Geological Survey, unpub. data, 2007).

Though capture probabilities of depletion seining samples for some nonnative fish is very high, the effect of a removal program using seines to target backwaters is not clear. The effectiveness of seining is unknown because of several factors, including (1) the relative importance of backwaters to native and nonnative fish is unknown; (2) the method will result in only the removal of individual nonnative fish occupying backwaters, which represent only a small fraction of habitat in Grand Canyon; (3) monitoring the effect of removal will be problematic because of unknown immigration, emigration, recruitment, and survivorship rates of fish in both backwaters and other nearshore habitats. Seining may be better applied to detecting newly invading nonnative fish and tracking changes in nonnative fish species distribution (see Occupancy Modeling section below).

Channel Catfish Pilot Project

Channel catfish, which are present in Grand Canyon, prey on native fish, and are adapted to warmer waters (such as have been released from Glen Canyon Dam in recent years), are generally agreed to be one of the nonnative fish species posing risk to native fish in Grand Canyon. Capture of channel catfish, especially in large rivers, is challenging because of the habits and habitat preferences of this species (Ryden and others, 2005; Davis and Furr, 2008). Arizona Game and Fish Department, in cooperation with the GCMRC, launched a pilot project to investigate channel catfish capture methods below Diamond Creek in June 2007 and July 2008 (Arizona Game and Fish Department and U.S. Geological Survey, unpub. data, 2007 and 2008). Gears tested included angling, electrofishing, and baited hoop nets. Although capture probabilities for these methods have not been determined, preliminary results suggest that a combination of a different hoop net (“catfish net”) and bait type (stink cheese) may result in greater numbers of channel catfish captures when compared to the standard hoop nets used for mainstem monitoring. Standard hoop nets baited with Aquamax pellets (216 samples) set below Diamond Creek in May 2006 captured two channel catfish; however, approximately 320 channel catfish were captured in catfish nets baited with stink cheese. Captures ranged from 0 to 25 channel catfish in one net (180 samples). Deploying catfish nets for 2 d without disturbing them also appeared to enhance channel catfish captures. Angling may be an adequate method for assessing trend information and is being implemented as part of the mainstem monitoring protocol for comparison with other methods. Electrofishing was not effective in capturing channel catfish in the Grand Canyon (Arizona Game and Fish Department and U.S. Geological Survey, unpub. data, 2007 and 2008).

In 2008, the pilot study focused on attempting to assess the capture probability of channel catfish hoopnets and stink cheese below Diamond Creek. Unfortunately, channel catfish captures were 75 percent less than those encountered the previous year, making estimation of a capture probability infeasible (R. Rogers, Arizona Game and Fish Department, pers. commun., 2008). Estimation of a capture probability for this method is important for determining the applicability of this method for targeted removal efforts and population monitoring of channel catfish. As results become available, this information should be incorporated into nonnative fish planning approaches.

Sonic Telemetry

Telemetry techniques have been applied in Grand Canyon to track fish movement with varying results. Radio tags were implanted in adult humpback chub in the proximity of the Little

Colorado River, but once the tagged fish reached a depth greater than approximately 4.5 m (Valdez and Ryel, 1995), they could no longer be detected. Sonic tags have recently been tested in Grand Canyon and the results appear promising (Hilwig and Makinster, in press). Up to 85 percent of sonic tagged fish were detected by manual tracking. Locations of sonic tagged fish can be determined within a few meters using manual tracking, allowing the ability to assign generalized habitat characteristics to the sample point. Large-scale movement can also be observed using tag location information. Recent sonic telemetry studies in Grand Canyon used sonic tags to assess the capture probability of channel catfish hoopnets baited with stink cheese, to determine the impact of the 2008 high-flow experiment on rainbow trout movement in Lees Ferry, to investigate habitat use by flannelmouth sucker, and to assess the feasibility of a broad-scale sonic tagging project in the mainstem Colorado River. Sonic technology has been greatly improved and customized for Grand Canyon conditions as a result of these projects.

This technique can be used, with some limitation, to track and compare movement patterns and habitat associations of nonnative and native adult and juvenile fish larger than 160 mm (See Remote PIT Tag Detectors section for smaller fish movement). Determining movement patterns and habitat associations will help to identify areas important for spawning, determine spatial and temporal overlap of native and nonnative fish, and assist scientists in evaluating the nature of the negative impacts nonnative fish impose on native fish. This information will assist in the development of nonnative control prescriptions to benefit and minimize impacts on native fish.

Remote PIT-Tag Detectors

Many of the fish in Grand Canyon are tagged with a passive integrated transponder (PIT) tag when they are captured during various sampling projects. These tags can be detected using a remote PIT-tag detector positioned on the riverbank, which logs tagged fish as they swim by and are detected by a submerged antenna. Arizona Game and Fish Department, in cooperation with the GCMRC, constructed three single-antenna remote PIT tag detectors. In 2008, two of the three antennas ran continuously from summer to early fall, with the exception of periodic technical issues. These remote PIT tag detectors recorded a total of 1,913 PIT-tags, 840 of which were unique fish.

In 2009, USGS Columbia River Research Lab joined the project and assisted in the installation of a multiplexing remote PIT-tag detector with multiple antennas (MUX) that span a large portion of the width of the Little Colorado River. This design can allow for an estimation of tag detection probability vital to evaluate the efficiency of the MUX as well as humpback chub monitoring effectiveness.

Currently, the installation and operation of this device is experimental and primarily focused on learning about humpback chub movement patterns in the Little Colorado River. However, this method has many applications to nonnative fish. Remote detection of PIT-tagged fish can assist scientists in comparing movement patterns of fish using the Little Colorado River. From this information, the timing and location of nonnative fish removal programs could be pinpointed to target nonnative fish vulnerabilities. As results become available, this information should be incorporated into nonnative fish planning approaches.

Bright Angel Creek

In 2002, Grand Canyon National Park initiated a trout removal project in Bright Angel Creek. Over the duration of this project, cooperators included SWCA Environmental Consultants and the U.S. Fish and Wildlife Service. This effort included the use of a weir near the mouth of the creek and serial depletion samples using backpack electrofishing units in proximity to the weir and around the confluence of Bright Angel Creek and Roaring Springs. This project was initiated because of increased captures of adult brown trout in the mainstem in the proximity of the Bright Angel Creek confluence relative to other areas of the mainstem (Leibfried and others, 2003; Leibfried and others, 2005) and concern for the impact brown trout may exert on native fish in the area. The high number of brown trout captured in the mainstem adjacent to the Bright Angel Creek confluence suggests that this tributary is important for brown trout spawning or is otherwise important for brown trout in the Grand Canyon (Leibfried and others, 2003; Leibfried and others, 2005).

During operation of the weir, brown trout captures declined significantly between 2003 and 2007. From November 2002 to January 2003, 423 brown trout and 188 rainbow trout were captured in the weir (Leibfried and others, 2003; Leibfried and others, 2005). From November 2006 to January 2007, a decline was observed, with 54 brown trout and 36 rainbow trout captured. However, this is consistent with a notable decline of rainbow trout (fig. 5) and brown trout catch rates in the mainstem (Ackerman, 2007; Rogers and others, 2008). Disentangling which factor or factors—mainstem mechanical removal of trout, removal of brown trout in Bright Angel Creek, or warm mainstem water temperatures—are the ultimate causes of trout reduction is not possible without additional information (Coggins, 2008). However, the weir proved to be effective in capturing the majority of brown and rainbow trout moving into Bright Angel Creek from the mainstem, including adult trout in spawning condition (Leibfried and others, 2003; Leibfried and others, 2005; Sponholtz and VanHaverbeke, 2007).

As part of this project, Bright Angel Creek was surveyed in two locations: (1) from the weir to Phantom Creek (3.0 km) and (2) in a 1.7-km reach in the headwater area of the creek near Roaring Springs. The fish captured in the lower reaches of Bright Angel Creek include native speckled dace, native bluehead sucker, and nonnative brown and rainbow trout (Sponholtz and VanHaverbeke, 2007). In the upper reaches, fish captures consisted entirely of brown and rainbow trout, including possible rainbow-cutthroat trout hybrids (SWCA Environmental Consultants, 2006). Serial depletion backpack shocking in Bright Angel Creek below Phantom Creek resulted in an estimated average removal efficiency of 85 percent for brown trout and 91 percent for rainbow trout in the sampling area during three electrofishing passes (Sponholtz and VanHaverbeke, 2007). Removal efficiencies in the headwater areas using backpack shocking were estimated to range from 38 to 56 percent for each electrofishing pass (SWCA Environmental Consultants, 2006). In 2003, brown trout and rainbow trout composed 40 and 50 percent, respectively, of the trout captures using electrofishing (extrapolated from Leibfried and others, 2003) below Phantom Creek. In 2006, brown trout and rainbow trout composed approximately 25 and 75 percent, respectively, of the trout captures using electrofishing (Sponholtz and VanHaverbeke, 2007). This suggests that the brown trout composition may have been reduced by removal of brown trout during periodic operation of the weir in combination with backpack electrofishing.

In spite of disrupting upstream migration of brown and rainbow trout in spawning condition as the result of the weir, small life-history stages of trout were captured in Bright Angel Creek (Sponholtz and VanHaverbeke, 2007; SWCA Environmental Consultants, 2006), suggesting continued juvenile recruitment from sources within the creek. The length frequency of rainbow trout captured with electrofishing has changed little, with a juvenile cohort (about 100 to 160 mm) representing approximately 90 percent of rainbow trout captured in 2006 and an adult cohort (about 240 to 300 mm) representing the remaining 10 percent. However, the length frequency of brown trout captured in the lower reaches of Bright Angel Creek during backpack shocking surveys shifted toward smaller individuals in 2007. In 2003, two cohorts were distinguishable for brown trout captures using backpack electrofishing. The juvenile cohort (about 70 to 130 mm) composed 55 percent of brown trout captured. A second cohort (about 190 to 250 mm) composed 25 percent of brown trout captured, with the remaining 20 percent being greater than 250 mm (n = 124) (National Park Service, unpub. data). In a similar survey conducted in 2006, only one cohort is represented (about 100 to 175 mm), representing more than 95 percent of brown trout captured (n = 158) (Sponholtz and VanHaverbeke, 2007). Catch-rate information for trout was not available for relative abundance comparisons among years. The shift to a single juvenile cohort of brown trout in 2006 indicates that spawning is still occurring in Bright Angel Creek despite the removal of large adults and suggests that juvenile brown trout growth rates may have increased because of assumed reduced density.

Construction and operation of a weir could potentially be applied to capturing trout species in many of the tributaries in Grand Canyon. The operation of the weir in combination with backpack electrofishing to remove trout from Bright Angel Creek was beginning to show signs of potential effectiveness. Bright Angel Creek continues to represent a potential source of brown trout into the mainstem. Further analysis of available data is warranted to determine potential effects of this project on the abundance of brown trout in the confluence area. As results become available, this information should be incorporated into nonnative fish planning approaches.

Shinumo Creek

Grand Canyon National Park, in cooperation with SWCA Environmental Consultants, initiated a native fish habitat restoration project in Shinumo Creek from 2004 to 2005. This project involved a rainbow trout reduction feasibility assessment in preparation for translocation of humpback chub into the creek. Valdez and others (2000) recommended implementation of nonnative fish management before attempting translocations of humpback chub into Grand Canyon tributaries. The feasibility assessment at Shinumo Creek suggested that backpack shocking would be most effective in capturing rainbow trout in the upper reaches of the creek (Leibfried and others, 2004; More information on trout relative abundance, distribution, and backpack electrofishing removal efficiency is available from Grand Canyon National Park.).

Rainbow trout have been captured throughout Shinumo Creek (Allan, 1993) and in the mainstem in proximity to the confluence area (Rogers and others, 2008). Similar to the Little Colorado River humpback chub aggregation, rainbow trout are likely to negatively affect humpback chub in the Shinumo Creek inflow aggregation identified by Valdez and Ryel (1995). Studies that directly link rainbow trout originating from Shinumo Creek to the mainstem have not been conducted. However, it appears possible that rainbow trout could be displaced from the creek into the mainstem during flood events. For example, reconnaissance sampling conducted by Grand Canyon National Park, SWCA Environmental Consultants, and Grand Canyon Wildlands Council in Clear Creek resulted in no rainbow trout captures where rainbow trout had been common previously (Maddux and others, 1987). This indicates that trout had likely been displaced from the creek during the winter floods of 2005 (More results are available from Grand Canyon National Park.). Although the fate of displaced trout is unknown, this suggests a mechanism by which trout from tributary streams may contribute to mainstem populations.

During 2009, GCNP led efforts to reduce rainbow trout using electrofishing in the lower 3 km of Shinumo Creek in preparation for a humpback chub translocation project. A translocation of 300 humpback chub was completed in June 2009. Further evaluation of the efficacy of backpack electrofishing to reduce rainbow trout abundance in Shinumo Creek is warranted as data become available and this information should be incorporated into nonnative fish planning approaches. However, further electrofishing in Shinumo Creek to test the effectiveness of mechanical removal of rainbow trout is subject to U.S. Fish and Wildlife Service permits.

Food Base Studies

In 2006, the GCMRC, in cooperation with Loyola University, University of Wyoming, and Idaho State University, began a research project to estimate the relative importance of the various food resources to fish in the Grand Canyon ecosystem to establish the degree to which native fish are limited by food resources (Rosi-Marshall and others, 2008). Investigators are measuring the supply of basal food resources such as primary production by riverine algae, inputs from Lake Powell, and litterfall from riparian vegetation as well as the rates of secondary production of macroinvertebrates in the river system. To establish trophic relationships, measurements of macroinvertebrate gut contents and stable isotopes are taken to determine energy flow from basal food resources to macroinvertebrates. Ultimately, the combination of all the above measurements with fish production, diets, and isotope composition will provide an estimate of the energy flow to native fish such as humpback chub, flannelmouth sucker, and common nonnative species such as common carp, fathead minnow, and rainbow trout.

These data will allow for estimates of the dominant food sources for these fish and estimates of potential food limitation and competition among native and nonnative species. Measurements of food resource production and inputs, secondary production, and energy flow in the food web will provide a basis for developing hypotheses and a monitoring plan that can help guide adaptive management strategies focused on threatened native fish species (Rosi-Marshall and others, 2008). As results become available, this information should be incorporated into the development of the nonnative fish risk assessment.

Experimental Stream Studies

The GCMRC, in cooperation with Loyola University Chicago, initiated a study to determine the potential impacts of water temperature and variable velocity on lower trophic levels of aquatic ecosystems. Cooperators are studying the response of algae and invertebrates in artificial streams to conditions that mimic (1) the daily changes in velocity from Glen Canyon Dam hydropeaking (constant-velocity with low and high daily fluctuations) and (2) predicted release temperatures below Glen Canyon Dam with a selective withdrawal structure (10 and 15ºC). Algae and *Gammarus lacustris* (an amphipod crustacean) from Lees Ferry and a black fly species closely related to those in Lees Ferry were used in the experiments.

Preliminary results indicate that water temperature had a strong and positive effect on algal biomass, algal chlorophyll, net primary production, and individual growth rates for larval black flies (T. Kennedy, U.S. Geological Survey, oral commun., 2009). Collectively, preliminary results indicate that increases in the water temperature along the Colorado River could lead to a significant increase in the biomass and production of food items that are important to fish, particularly those species that are common along downstream reaches. Additionally, daily fluctuations in water velocity do not appear to have adverse impacts on algae or invertebrates (T. Kennedy, U.S. Geological Survey, oral commun., 2009).

Integration of the results from the food base and flume studies will assist in determining factors such as food limitation and subsequent competition that may contribute to the negative impacts nonnative fish place on native fish. Identification of the conditions that cause predation or competition among species will assist scientists in developing nonnative fish control prescriptions that may minimize these negative interactions. As results become available, this information should be incorporated into the development of a nonnative fish risk assessment.

Summary of Fish Projects

The ability to capture nonnative fish and detect changes in their abundance and distribution is vital to developing management plans and prioritizing nonnative management efforts. If changes in the status of nonnative fish are not detected, then a rapid response to reduce nonnative species abundance is compromised. Review of the fish-sampling activities in Grand Canyon reveal several information needs as well as promising options for developing nonnative fish monitoring and control approaches.

Currently, effective mainstem nonnative fish monitoring programs are in place for rainbow and brown trout and possibly common carp. Effective monitoring in not ongoing for other prominent nonnative fish species in the mainstem Colorado River, including fathead minnow, red shiner, channel catfish, bullhead spp., green sunfish, smallmouth bass, and striped bass. This limitation is likely the result of widely varying and sometimes low frequency of the capture of these species, which is exacerbated by the low capture efficiency of gears currently used in Grand Canyon fish sampling activities. Lack of robust monitoring data results in an inability to (1) identify changes in nonnative fish populations that warrant control actions, (2) detect newly invading species, and (3) evaluate effectiveness of removal programs. The development of a mainstem nonnative fish monitoring protocol to detect changes in abundance and distribution of the nonnative fish listed above is a necessary step towards addressing nonnative fish control approaches. Monitoring activities should initially be conducted in proximity to humpback chub aggregations and tributary inflows.

With the exception of the Little Colorado River, there are currently no fish monitoring programs in place within the tributaries of Grand Canyon. Sampling in tributaries has been sporadic and extensive sampling in tributaries only occurred in the mid 1980s, early 1990s and in 2004 and 2005. Tributary streams in Grand Canyon contain both native and nonnative fish; however, the diversity of nonnative fish found in tributaries warrants concern because tributaries are likely sources of nonnative fish to the mainstem Colorado River. Development of a tributary fish monitoring protocol to detect changes in the abundance and distribution of nonnative fish currently present in tributaries and to detect new invading fish species is necessary for addressing nonnative fish control in Grand Canyon.

Lees Ferry is an area where new nonnative species introductions can be anticipated. The ability to detect new fish species in Lees Ferry is an issue because the invader can then disperse throughout the entire river system below Glen Canyon Dam. Currently, there are no monitoring programs in place dedicated to the detection newly invading nonnative fish in Lees Ferry or Grand Canyon, although, standard Lees Ferry monitoring protocols may be adequate for detecting adult smallmouth bass and walleye. Currently, the method developed to target YOY rainbow trout in Lees Ferry represents the only method available for detecting the presence of YOY nonnative fish such as channel catfish, smallmouth bass, and green sunfish in this reach. This method will be incorporated into a monitoring protocol to detect new invading fish species or recruitment of existing nonnative fish in Lees Ferry in 2010. This method could also provide information for the development of river-wide nonnative fish monitoring protocols in the future.

Two techniques have been tested that show promise in evaluating movement patterns of native and nonnative fish: (1) acoustic telemetry to track individual fish movement and (2) remote PIT-tag detectors. Manual tracking of acoustic tags can be used to track fish (>160 mm) movement to specific locations. Remote PIT-tag detectors can be used to track fish (>100 mm) movement patterns within tributary streams. Comparing movement patterns will allow scientists to identify special and temporal conflicts among native and nonnative species. This will assist in the development of control prescriptions targeting vulnerabilities of nonnative fish while benefiting native fish.

Removal methods attempted in Grand Canyon showing promise for nonnative fish control applications include: (1) electrofishing to reduce mainstem trout abundance and potentially smallmouth bass and walleye; (2) catfish hoopnets baited with stink cheese to capture channel catfish; (3) weirs, angling, and backpack electrofishing to reduce trout abundance in tributary streams. Although these methods may not result in efficient removal of nonnative species in some cases, they are the only techniques currently available to attempt nonnative fish control. No other methods have been determined to be consistently feasible or more effective in capturing presumably rare nonnative fish in Grand Canyon. Many techniques have been attempted to capture rare nonnatives, including slat traps, fyke nets, bow-fishing, electrofishing settings specific for catfish, trot lines, standard and experimental gill nets, trammel nets of various mesh sizes, and bag seines, to name a few. To date, very few tools have been proven adequate for application to nonnative fish control in Grand Canyon. The GCMRC and its cooperators will continue to investigate and refine effective methods for monitoring and control of nonnative fish in Grand Canyon.

Biologists conducting the nearshore ecology project are attempting to quantify abundance, survival, habitat use, growth, and natal source of juvenile humpback chub over three flow periods. Based on the 2008 pilot studies, information on fathead minnow abundance and habitat use in the study area may also be periodically obtained (M. Yard, U.S. Geological Survey, oral commun., 2009). Techniques and insights developed by this project will help to (1) identify habitat overlap and potential competition juvenile humpback chub may experience from fathead minnows, (2) develop effective systemwide nonnative fish monitoring protocols, and (3) detect natal sources of nonnative fish.

In addition to fish sampling projects, food base studies are underway in Grand Canyon. Food base studies include the field measurement of food sources and trophic relationships. Additionally, scientists are using temperature and water level fluctuation simulations in an artificial stream to evaluate the impacts of these factors on lower trophic levels of the Grand Canyon food web. Integration of the results from the food base and experimental stream studies will assist in determining factors that may adversely affect natives such as food limitation and subsequent competition among native and nonnative fish. Additionally, the GCMRC is currently incorporating this information into an ecosystem model to identify limiting factors in humpback chub recruitment dynamics including food base and temperature limitation and predation or competition. Valdez and Speas (2009) evaluated the benefits of three temperature scenarios on potential fish spawning, incubation, and growth in Grand Canyon. They determined that warming release temperatures had the potential to benefit all native fish in Grand Canyon, however, these conditions were also suitable for seven out of ten warmwater nonnative species examined. Identification of the mechanisms that potentially limit humpback chub recruitment will assist scientists in developing nonnative fish control prescriptions that may minimize negative impacts on juvenile humpback chub. The GCMRC is currently developing and ecosystem model to assist in the identification of these mechanisms. As results become available, this information should be incorporated into nonnative fish control planning and the development of a nonnative fish risk assessment.

Approaches to Nonnative Fish in Grand Canyon

The information presented above provided the basis for developing the recommendations and optionss for nonnative fish monitoring, research and control in Grand Canyon that follow. There is an immediate need to address known issues of native fish conservation in Grand Canyon while improved nonnative fish capture and control strategies are being developed. The objective of this ~~plan~~document is to review fish-related programs conducted in Grand Canyon and provide prioritized suggestions for (1) monitoring improvements, (2) nonnative control ~~methods~~ options available for use in Grand Canyon, (3) new research projects to address information needs, and (4) contingency planning and funding. These ~~recommendation~~options draw upon the experiences of other nonnative fish control programs, including the Upper Colorado River Endangered Fish Recovery Program and other programs around the world. These ~~recommendation~~options are consistent with GCDAMP management objectives and the HBCCP and address SSQs and INs related to nonnative fish in Grand Canyon. These ~~recommendation~~options are based on the best available science, information, and professional judgment (Persons and others, 2003; Francis and others, 2007). This approach should be revisited as necessary to incorporate new information from nonnative fish studies conducted in Grand Canyon, the results of other nonnative fish control programs, and new research information.

~~Recommendation~~Options presented~~made~~ here rely on nonnative species monitoring, research, and control methods that are readily available for implementation in the near future. ~~Recommendation~~Options presented here are prioritized based on discussions among fisheries scientists and cooperators participating in three nonnative fish workshops. Formulation of ~~recommendations~~ control options is hindered by the challenge of determining whether predation, competition, habitat alteration, or a combination of these mechanisms is most critical to consider. The GCMRC has made progress in developing an ecosystem model that will assist scientists in evaluating the nature of risks imposed to native fish by nonnative species and other factors. Identification of the nonnative species that pose the greatest threat to natives is vital for focused management plans that prioritize removal efforts. In the meantime, the criteria used to determine the nonnative species to be the focus of management efforts included (1) current occupancy in the mainstem Colorado River in Grand Canyon and proximity to the Little Colorado River, (2) perceived likelihood of population expansion, (3) known predators on fish, and (4) need for improved monitoring or removal methods.

Although it would be ideal to pursue all of the ~~recommendation~~options below for development of a comprehensive nonnative fish control strategy, it is unlikely that the GCDAMP, operating under a funding cap, could afford to do so. Agency managers, especially the Arizona Game and Fish Department, U.S. Fish and Wildlife Service, and National Park Service, should consult with GCDAMP committees to determine the scope and a logical order of control projects to be implemented each year during an annual meeting. Prioritization criteria will include known threats to natives, logistical feasibility (including shared logistics with other efforts), probability of success, degree of risk to natives, funding considerations, and permit requirements for Federal, State and Tribal agencies. Implementation of these ~~recommendation~~options will require agreement among management agencies as to their roles and responsibilities in managing nonnative fish and prioritization of control projects (See Implementation Strategies below).

Scientific Assumptions

Grand Canyon fish scientists and managers make the following assumptions regarding nonnative fish control planning (modified from Persons and others, 2003). These assumptions are reflected in more specific ~~recommendation~~options that follow.

- Nonnative fish negatively affect native fish through predation and competition and are a major threat to the persistence of native fish in Grand Canyon.
- Removal or reduction of nonnative fish populations will be of some benefit to native fish.

- To increase effectiveness and efficiency, nonnative fish control planning will consider sources of nonnatives such as tributaries, streams, and reservoirs within Grand Canyon and Colorado River watersheds.
- Control strategies will not eliminate nonnative fish from Grand Canyon and will require multiple and persistent control actions through time to be effective.
- Nonnative fish are not the sole factor negatively impacting humpback chub in Grand Canyon, although, nonnative fish control may result in benefits to native fish.
- The negative impacts of nonnative fish on native fish can be synergistic when interacting with other factors such as flow regimes, water quality, and pathogens that may also exert negative impacts.
- The Colorado River ecosystem is a dynamic environment where continued change can be expected, meaning the threats from nonnative fish can be expected to change over time and, species that pose the greatest threats to native species may also change.

Strategic Issues

As management agencies begin to prioritize nonnative fish control efforts and define their roles in the overall effort, there are a number of issues, or threats, that need to be considered. Based on the data about fish captures in Grand Canyon presented above, a review of current monitoring protocols, and discussions with scientists and managers in this and other nonnative fish management programs around the world, a list of issues is presented below. The issues presented below identify nonnative species and geographic targets of concern and information and programmatic needs for nonnative fish control planning upon which recommendations and options presented below have been developed. This list provides the basis for strategic planning and, in the case of the mechanical removal project, implementation of nonnative fish research recommendations and control ~~recommendation~~options. This list should be revised as new information is gained. The GCDAMP will likely address some, but not all, of these issues. Management agencies will need to work with the GCDAMP and each other to determine the level of risk from these threats they are willing to accept and how they may be able to accomplish control and management actions to address threats deemed important.

- Address abundance of rainbow trout in proximity of the Little Colorado River that may impact young humpback chub in the mainstem
- Address recent increase in captures of channel catfish and bullhead in the Little Colorado River area that may impact young humpback chub in the tributary and the mainstem
- Address brown trout production in Bright Angel Creek that may impact native fish in tributaries and the mainstem
- Address potential upstream movement of warmwater nonnative fish, including striped bass, from below RM 236 and Lake Mead that may impact native fish in the mainstem
- Identify sources of nonnative fish into Grand Canyon, including spawning areas, reservoirs, dam passage, tributary inputs, and illegal stocking, which may impact native fish in tributaries and the mainstem
- Prevent new nonnative fish species invading Grand Canyon from Lees Ferry and other sources

- Identify the mechanisms and nonnative species posing the greatest negative impact on juvenile humpback chub
- Improve nonnative fish monitoring methods, early detection protocols, and capture methods
- Need for management agency involvement in the implementation of control programs
- Consider scenario presented by Valdez and Speas (2009) regarding temperature suitability and species of concern (brown and rainbow trout, walleye, smallmouth bass, and redside shiner)

Regulatory Authority

The implementation of the monitoring and research recommendations and control options presented in this ~~plan~~document will require coordination, consultation, or compliance with agency and tribal governments. Agencies include the National Park Service, Arizona Game and Fish Department, U.S. Fish and Wildlife Service, and Tribes with ties to the Grand Canyon. Research permits are required by GCNP to conduct work within the national park boundaries. The Arizona Game and Fish Department requires scientific collection permits for species under their jurisdiction, including nonnative fish and native fish that are not federally protected. The U.S. Fish and Wildlife Service requires permits when projects may result in the harm of endangered species. Tribal authorities require permits for scientists to conduct work and collect species within tribal boundaries. Implementation of monitoring and research recommendations and options within this document may also trigger consultation and compliance requirements associated with the Endangered Species Act, National Environmental Policy Act, National Historic Preservation Act and Federal-Tribal Trust Responsibilities. Cultural values are recognized to conflict with -options and recommendations presented in this document (See Tribal Concern section below). Necessary consultation and compliance will be the responsibility of appropriate management agencies.

Monitoring Recommendations

The current state of nonnative fish monitoring Grand Canyon limits the ability of scientists and managers to identify risks posed to native fish from changes in the abundance and distribution of several nonnative species or invasions of new species. This situation means threats may go undetected. Further, failure to promptly detect expansions of nonnative fish abundance and distribution may increase the costs and decrease the effectiveness and feasibility of control. This section focuses on improving monitoring and detection, the core components of implementing and evaluating removal strategies. These recommendations are presented in their order of importance.

Mainstem Monitoring

Mainstem monitoring using electrofishing is effective at monitoring trends in rainbow trout, brown trout, and potentially common carp, as well as some native fish. Other nonnative fish species such as channel catfish, bullheads, striped bass, and small-bodied fish are not effectively monitored using this protocol. Current mainstem monitoring protocols should be continued to monitor the suite of species for which the method is effective. However, application of other sampling methods should be considered. Information collected by expanding the current mainstem monitoring program to include a multitude of sampling gears would assist in the development of an occupancy model (see Research Recommendations below). Sampling methods may include slow shocking, trammel netting, seining, minnow traps, electric seines, fyke nets, angling, and large mesh gill nets. Each method should be evaluated for logistical feasibility and safety of deployment in Grand Canyon. Monitoring improvements should initially be attempted in proximity to humpback chub aggregations and tributary inflows. While new nonnative fish-capture and monitoring protocols are being developed, mainstem electrofishing should continue as it provides the best nonnative fish monitoring information available at this time. Investigation of several maistem sampling methods near humpback chub aggregations and tributary inflow areas is planned for 2010 (See GCMRC FY2010–2011 budget and work plan). This recommendation addresses CMIN 2.4.1 and RINs 2.4.1, 2.4.3, and 2.4.6 and HBCCP recommendations.

Early Detection Monitoring at Lees Ferry

Lees Ferry is very likely to experience nonnative fish invasions or introduction resulting from dam passage, illegal stocking, distribution from the -12 mile slough, and even contributions from the Paria River. The slow shocking technique used to target early life-history stages of trout in the Lees Ferry reach has resulted in captures of small green sunfish and smallmouth bass. Lees Ferry trout monitoring using a standard electrofishing method is conducted three times per year and has resulted in captures of adult smallmouth bass and walleye. Continuing monitoring for early life-history stages and developing an invasive fish monitoring program for Lees Ferry (to include -12 mile slough) will increase the likelihood of early detection and rapid response of newly invading or expanding nonnative fish populations in Lees Ferry.

Incorporating the slow-shocking technique into the Lees Ferry monitoring program and developing an invasive fish monitoring program (to include -12 mile slough) is recommended. This activity is planned as part of Lees Ferry monitoring efforts in 2010 and 2011 (See GCMRC FY2010–2011 budget and work plan). These recommendations address CMIN 2.4.1 and RINs 2.4.1, 2.4.3, and 2.4.6 and HBCCP recommendations.

Fish Monitoring in Grand Canyon Tributaries

With the exception of the Little Colorado River, there are currently no fish monitoring programs in place for Colorado River tributaries in the immediate vicinity of Grand Canyon. Tributaries known to contain nonnative fish, including the Paria River and Bright Angel, Shinumo, Tapeats, Kanab, and Havasu Creeks, should be included in a monitoring program. Developing monitoring protocols for these tributaries and confluence areas will not only assist in evaluating the condition of and changes in the fish communities found in these tributaries, but also will aid in the detection of new invaders into the Colorado River ecosystem. This information would assist scientists in assessing potential sources of nonnative fish into the mainstem and identifying areas that are potentially important for spawning and recruitment of native and nonnative fish. Identifying new invaders in tributaries before they reach the mainstem could provide opportunities to more efficiently control newly introduced species compared to attempting control in the mainstem. Data collected in tributary streams should be maintained in a centralized and accessible database similar to that of the data collected during most mainstem and Little Colorado River sampling efforts.

Implementing a fish monitoring program in Grand Canyon tributary streams is recommended. This recommendation addresses SSQ 1-7, CMIN 2.4.1 and RINs 2.4.1, 2.4.3, 2.4.5 and 2.4.6 and HBCCP recommendations.

Nonnative Fish Removal ~~Recommendation~~Options

The Grand Canyon presents a variety of logistical challenges to implementing nonnative fish control strategies. Here we ~~make recommendations~~develop options for nonnative fish control in Grand Canyon based on previous successes and experiments conducted in Grand Canyon and other national parks. These ~~recommendation~~options represent techniques that have the greatest likelihood of reducing nonnative fish abundance in particular areas of Grand Canyon. Due to tribal concerns for culturally sensitive areas such as the Little Colorado River and the taking of life, development and implementation of -nonnative fish ~~removal~~ control projects must be discussed among the management agencies and the tribes (See Regulatory Authority above and Tribal Concerns below). Removal ~~recommendation~~options are listed in the order of priority.

Mechanical Removal in the Little Colorado River Reach

In considering the continued use of mechanical removal of nonnative fish in the Little Colorado River reach several factors require consideration. First, the unplanned release of warmer water from Glen Canyon Dam is highly correlated with both a decrease in nonnative abundance (Coggins, 2008) and an increase in the Grand Canyon population of humpback chub (Coggins and Walters, 2009). However, in a hypothetical modeling scenario developed using trout diet information (Yard and others, in prep.) assessed the impact removed trout might have had on humpback chub had they not been removed. Assuming that trout captured during mechanical removal were not removed, and fish abundance and catchability conditions remained the same during the diet study period, the number of humpback chub that could have been consumed these trout had they not been removed would be approximately 12,169 over 1.76 year diet study period (2003-2004). Thus, it is still unclear that mechanical removal of nonnative fish is benefiting native fish.

As a result, continued large-scale experimentation will be required to understand what factors benefit native fish, although, modeling approaches may help answer these questions. Second, if managers decide to maintain depressed nonnative populations, an ongoing strategy of control must be developed. Given the essentially fixed cost of removal efforts and fixed capture probability, the per capita removal expense increases as nonnative abundance falls. This implies that complete removal of nonnative species, if even possible, would require a huge expense.

With this in mind, it is logical to establish a non-zero target abundance of nonnative fish and periodically apply control efforts to achieve that level. Unfortunately, defining this target in a scientifically credible manner is daunting. Completion of this task presumes a level of understanding of the direct and indirect mortality sources on native fish from nonnative fish that may not be attainable. Although simple models such as those developed by Paukert and Petersen (2007) may provide some guidance on the strength of predatory and competitive interactions, it will still be necessary to define targets in some fashion. For instance, if the most important negative interaction between rainbow trout and humpback chub is presumed to be competition for food, the question becomes: how much more food do humpback chub need? Similar arguments can be made relative to predatory interactions between rainbow trout and humpback chub. To what degree should the predatory mortality rate be reduced? Although the GCMRC is constructing more elaborate models of ecosystem dynamics, these models will still need to be tested to confirm basic model assumptions.

While GCMRC constructs these models, scientists and managers should recognize that defining this target is predominantly an exercise in risk management rather than an implicit scientific question. It may be acceptable to arbitrarily define and maintain a low level of rainbow trout abundance (for example, 10 to 20 percent of January 2003 rainbow trout abundance) and continue monitoring to determine trends in native fish abundance and recruitment. The necessity of removing large portions of nonnative predators to benefit native species is generally supported in the literature. In a review of the impact of nonnative fish on native razorback sucker (*Xyrauchen texanus*) and bonytail chub (*Gila elegans*) conducted by Pacey and Marsh (1998), the authors suggest the complete eradication of nonnative fish from pond environments is necessary for survival of native species in these habitats. Weidel and others (2002) conducted smallmouth bass removal in an Adirondack lake and determined that removal of 43 to 88 percent of the smallmouth bass resulted in a positive response in other fish species. Harding and others (2001) modeled the impact of removing the nonnative red fox on the endangered California clapper rail (*Rallus longirostris obsoletus*). The authors found that reduction of the fox population by 50 to 70 percent correlated with population growth of the rails in the following year. Dudley and Matter (2000), however, observed no increase in recruitment of Gila chub (*Gila intermedia*) when more than 90 percent of the nonnative green sunfish population was removed in isolated pools in a small desert stream. The authors indicated no YOY Gila chub were observed in both the experimental (no green sunfish) and control pools (green sunfish present). However, they observed abundant Gila chub YOY in other areas of the stream occupied by green sunfish, indicating a potential issue with the experimental design. These studies generally support the need for large reduction targets to affect a positive response in desired species. Setting long-term targets for nonnative fish removal will likely require continued investigation and refinement of removal strategies, continued monitoring of native fish response in the removal reach, and consideration of logistical and budgetary limitations.

If managers and scientists agree that the reduction target for rainbow trout in the Little Colorado reach is maintaining 10 to 20 percent of January 2003 rainbow trout abundance, a model developed by the GCMRC (L. Coggins, GCMRC, pers. commun., 2009) provides some guidance on the logistical requirements for achieving this goal. Reaching the 10 to 20 target in the Little Colorado River reach (approximately 600 to 1,200 rainbow trout) could be achieved with a minimum of two trips per year assuming a low immigration rate of rainbow trout into the Little Colorado River Reach (<50 fish/month; fig. 6). If immigration rates are higher (300 fish per month), then three or more trips per year will be required to maintain this abundance level (fig. 6).

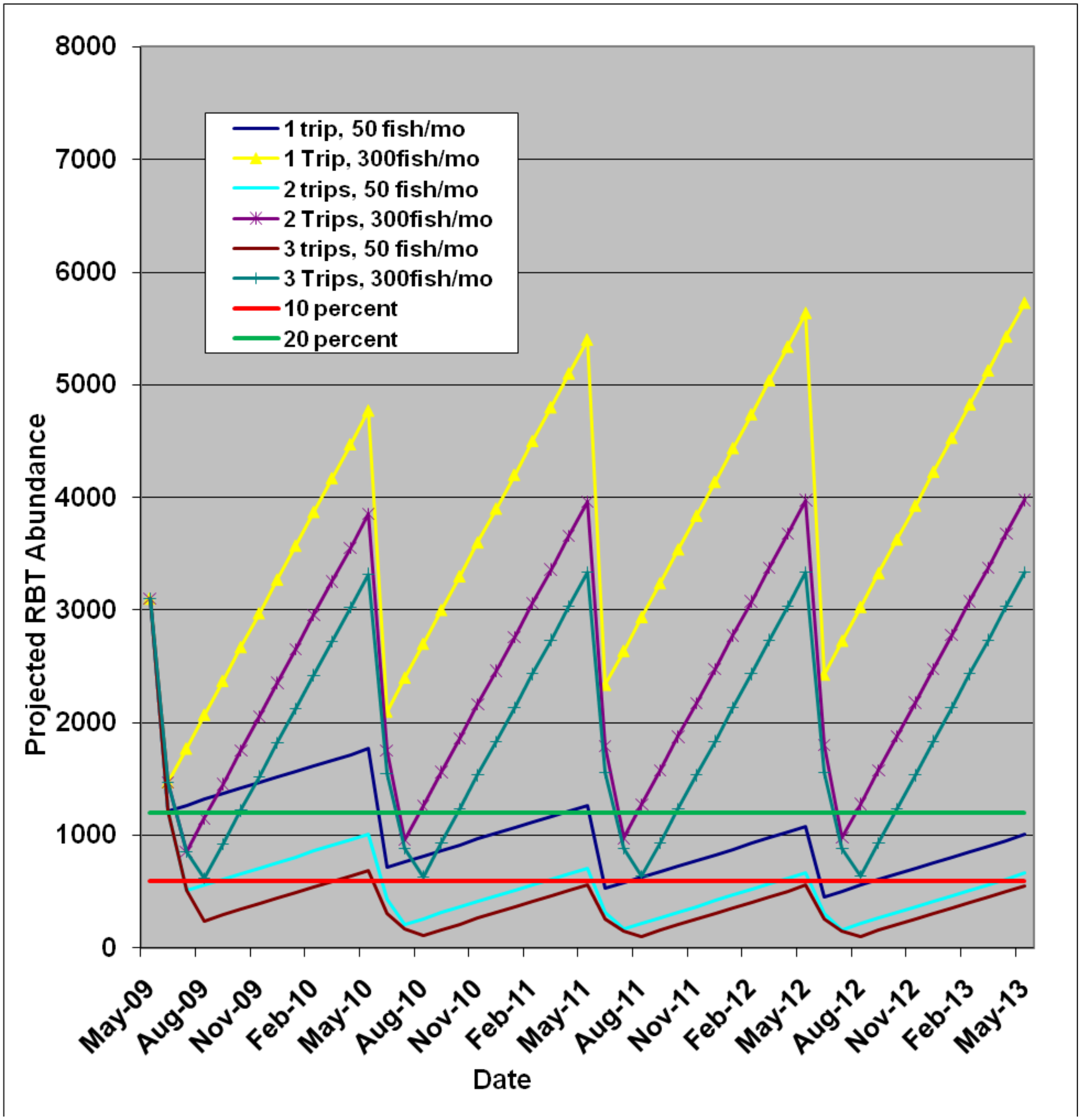


Figure 6. Projected number of trips required to maintain rainbow trout abundance in the Little Colorado River reach at 10 to 20 percent of the January 2003 level (600 to 1,200 fish). Target indicated by the bold horizontal lines.

Alternatively, managers may wish to commit to an annual level of spending on control efforts consistent with perceived risk and simultaneous attainment of other program objectives. These strategies are consistent with the general philosophy of adaptive management and recognize that mechanical removal actions are opportunities to increase knowledge while simultaneously maximizing benefit and minimizing risk to a focal resource. Consistent with the April 2007 workshop recommendation to maintain lower levels of predators and competitors in critical reaches to support humpback chub conservation (Grand Canyon Monitoring and Research Center, 2008), mechanical removal of trout in the proximity of the Little Colorado River confluence will be continued in 2010.

Maintenance of the rainbow trout abundance at 10 to 20 percent of January 2003 level in the Little Colorado River reach is ~~recommended~~warranted. Evaluation of the potential of mechanical removal above the Little Colorado River reach to reduce rainbow trout abundance downstream in the Little Colorado River reach should also be considered. While mechanical removal efforts in the LCR inflow reach may have contributed to the reduction of rainbow trout and other nonnative fish abundance, there are long-standing concerns by Native American stakeholders about conducting removal efforts in culturally sensitive areas such as the LCR. Additionally, mechanical removal efforts in this portion of the river are both financially and logistically demanding. As such, other alternatives to mechanical control in the Little Colorado River reach should be evaluated. Possible alternatives to reducing rainbow trout abundance in the Little Colorado River reach include conducting mechanical removal immediately below the Paria River, using flow manipulations to limit recruitment of nonnative fish, increasing turbidity through augmentation, and other strategies (See Research Recommendations below). This ~~recommendation~~option addresses SSQs A, B, and 1-4; CMIN 2.4.1; and RINs 2.4.1, 2.4.2, and 2.4.6; and EIN 2.4.1 and HBCCP recommendations.

Nonnative Fish Removal in Tributaries

Nonnative fish control is recommended in three Grand Canyon tributaries: Little Colorado River, Bright Angel Creek, and Shinumo Creek. Nonnative fish removal in these three tributaries is recommended based on the availability of recent sampling information, likelihood of effective nonnative fish control methods, and the presence of native fish. The Little Colorado River was selected because of its importance for humpback chub spawning (Kaeding and Zimmerman, 1983; Paukert and others, 2006) and its potential as a source of warmwater nonnative fish into Grand Canyon (Stone and others, 2007). Bright Angel Creeks was selected because data indicates that it is a source of nonnative trout species into the mainstem (Leibfried and others, 2003) and it contains native fish communities. Shinumo Creek was selected because it is a humpback chub translocation site; Valdez and others (2000) recommended the implementation of nonnative fish management before attempting translocations of humpback chub. Tapeats Creek was not selected because of the lack of information identifying this tributary as a source of nonnative fish to the mainstem. Initiating nonnative fish control efforts in Little Colorado River, Bright Angel Creek, and Shinumo Creeks to benefit native fish residing within the tributary and reducing sources of nonnative fish into the Colorado River is recommended. This ~~recommendation~~option addresses SSQs A, B, and 1-7; CMIN 2.4.1; and RINs 2.4.1, 2.4.2, and 2.4.3 and HBCCP recommendations.

Shinumo Creek

Trout reduction in Shinumo Creek should be conducted with a combination of gears such as weirs, backpack shockers, hoopnets, and angling to reduce local nonnative fish abundance before additional translocation of native fish. Backpack shocking could be used in the summer months to capture rainbow trout in the upper reaches (above White Creek confluence area) where water temperatures are cooler, trout densities were greater (Leibfried and others, 2004), and the presence of translocated humpback chub would not be as likely. These control efforts may also be applied to manage contributions of rainbow trout to the mainstem and the potential negative effects on the

Shinumo inflow humpback chub aggregation. Reduction efforts should be focused on times when nonnative fish are most vulnerable to capture methods such as during low-flow conditions or spawning migrations. Temporary weirs placed throughout the creek could be used during the summer to target trout moving upstream to escape warming water temperatures in the lower reaches and could also target movement associated with spawning periods. For other nonnative fish removal ~~recommendation~~options in tributary streams, see the Chemical Renovation and Barrier Construction section below.

Investigation of continued nonnative fish removal in Shinumo Creek using backpack shocking, weir operations, and chemical renovation in combination with barrier construction is recommended. These ~~recommendation~~options address SSQs A, 1-4, and 1-7; CMIN 2.4.1; and RINs 2.4.1, 2.4.2, 2.4.3, 2.4.5, and 2.4.6 and HBCCP recommendations.

Bright Angel Creek

Bright Angel Creek may be a major source of nonnative brown and rainbow trout into the mainstem. These fish likely negatively affect native fish through predation and competition both near the Bright Angel Creek confluence and possibly more distant locations through dispersal and migration. Operation of a weir at the mouth of Bright Angel Creek in combination with backpack electrofishing samples appeared to impact the population structure of brown trout in the creek. Continued operation of the weir in Bright Angel Creek in combination with backpack shocking above the weir is recommended to remove upstream migrating brown trout and rainbow trout. These actions could assist in maintaining reduced rainbow and brown trout catch rates currently observed in the mainstem, complement removal efforts conducted near the Little Colorado River, and reduce resident trout abundance to benefit native fish found in Bright Angel Creek. Reduction should focus on times when nonnative fish are most vulnerable to capture methods such as during spawning migrations. These control efforts may also be applied to manage contributions of trout to the mainstem and the potential negative effects on the Bright Angel inflow humpback chub aggregation. For other nonnative fish removal options in tributary streams, see the Chemical Renovation and Barrier Construction section below.

Investigation of continued nonnative fish removal in Bright Angel Creek using backpack shocking, weir operation, and chemical renovation in combination with barrier construction is recommended. These options address SSQs A, 1-4, and 1-7; CMIN 2.4.1; and RINs 2.4.1, 2.4.2, 2.4.3, 2.4.5, and 2.4.6 and HBCCP recommendations.

Channel Catfish and Bullhead Species Removal in the Little Colorado River and Confluence Area

Several species of nonnative fish have been captured in the Little Colorado River since 1988 (Stone and others, 2007). In the early 1990s, the dominant species shifted from channel catfish and bullhead species to species in the minnow family, most notably common carp and fathead minnow (Gloss and others, 2005). However, in 2008, captures of channel catfish and bullhead species in the Little Colorado River and the mainstem were greater than previous years, indicating a potential increase in the abundance of these species in that area. Small life-history stages of common carp and channel catfish have been captured in the Little Colorado River, indicating possible spawning of these species in the lower reaches of the tributary or invasion of these individuals from upstream sources within the watershed (Stone and others, 2007). Channel catfish is a species of concern in Grand Canyon because of its potential to expand with warming water temperatures and its presence in the Little Colorado River, which could negatively affect the humpback chub aggregation found there.

The results of a nonnative fish pilot project conducted in 2007 and 2008 suggest that a combination of a different hoop net (catfish net) and bait type (stink cheese) may result in greater numbers of channel catfish captures than the methods currently used for fish monitoring. Although this technique has not been fully evaluated, it appears to be effective in capturing channel catfish and may improve the ability to monitor changes in channel catfish abundance. Further pilot testing to evaluate the feasibility of using catfish nets and stink cheese to reduce and monitor channel catfish and bullhead species in the Little Colorado River and the confluence area is warranted. However, scientists have expressed concern that the mesh size of the catfish net (1 ½”) could result in gilling and mortality of subadult humpback chub or other native fish.

In 2003, the Arizona Game and Fish Department conducted preliminary testing of capture methods for common carp and channel catfish in the Little Colorado River (Arizona Game and Fish Department and U.S. Geological Survey, unpub. data, 2007). These methods included hoop nets, angling, slat traps, bow fishing, and spearfishing and were tested in approximately the lower 2 km of the river. Further testing of these methods is recommended to determine capture efficiencies of the various gears and evaluate their applicability to monitoring and management of nonnative fish. Monitoring the effects of removal on channel catfish and bullhead population size structure is important. During a nonnative fish removal project conducted from 2002 to 2007 in the lower San Juan River using electrofishing, 11,581 channel catfish were removed, however, a significant decrease in the size structure of channel catfish also occurred (Elverud, 2008). Because the impacts that various life stages of nonnative fish have on native fish is poorly understood, monitoring native and nonnative population responses to removal efforts is important for minimizing unintentional impacts of removal.

Investigation is recommended of nonnative fish reduction and monitoring methods that do not impact humpback chub in the Little Colorado River and the confluence area. These ~~recommendation~~options address SSQs A and 1-7; CMIN 2.4.1; and RINs 2.4.1, 2.4.3, and 2.4.6 and HBCCP recommendations.

Chemical Renovation and Barrier Construction

Chemical renovations of rivers and streams using piscicides to control nonnative fish have benefited many threatened and endangered species. To increase the likelihood of success, these projects must be combined with a physical barrier in the channel to prevent reinvasion of nonnative fish from downstream sources and renovations of upstream sources of nonnative fish such as ponds or perennial pockets of water within the watershed. Chemical renovation may also involve capture of native and endangered fish for restocking after piscicides are detoxified. A combination of these nonnative fish control strategies and native fish conservation actions could be applied to Grand Canyon. Barrier placement should be carefully considered so as to minimize negative effects on native fish that may exhibit transient use of the tributaries. Barriers should be strategically positioned to minimize negative impacts and maximize benefit to native fish. For example, in the case of Bright Angel Creek, a barrier positioned above the campground could afford angling opportunities in areas of concentrated visitor use while reclaiming the upper reaches of the creek for native fish conservation (P. Sponholtz, US Fish and Wildlife Service, pers. commun., 2010)

Piscicides have been used to eradicate or control nonnative fish and protect endangered species in several national parks. To benefit native brook trout, antimycin A was used successfully in Great Smoky Mountains National Park to control of nonnative rainbow trout in small streams where mechanical removal by electrofishing was ineffective (Hammonds and others, 2006).

Renovations were conducted before translocation of brook trout. Researchers determined that the cost of chemical treatment was significantly less than previous unsuccessful removal attempts using backpack electrofishing in the same stream segment (Hammonds and others, 2006). Antimycin A is also being used in Yellowstone National Park to eradicate nonnative brook trout in tributary streams of Yellowstone Lake to protect native cutthroat trout (*Oncorhynchus clarki bouvieri*). The success of the renovations was attributed to proper piscicide application and detoxification, combined with natural barriers to upstream migration of nonnatives and translocation of native fish after renovation (Gresswell, 1991). Ten years of nonnative brook trout removal using piscicides and electrofishing in combination with barrier construction resulted in an almost threefold increase in abundance of native bull trout (*Salvelinus confluentus*) at Crater Lake National Park (Buktenica and others, 2001; Renner, 2005). In many of these cases, mechanical removal was determined to be ineffective in obtaining conservation goals. Mechanical removal also required greater long-term expenditures than chemical renovation and barrier construction.

Chemical renovation and barrier construction in tributary streams identified as sources of nonnatives, along with restocking and translocation of native species, are the preferred technical option for eliminating or reducing sources of nonnatives into the mainstem Colorado River. The risks of chemical renovation to native fish should be assessed before implementation. This ~~recommendation~~option addresses SSQs A, B, and 1-7; CMIN 2.4.1; and RINs 2.4.1, 2.4.2, and 2.4.3 and HBCCP recommendations.

Research Recommendations for Development of Nonnative Fish Control Strategies

Research into the biology of nonnative Grand Canyon fish, possible target strategies, and future control options will be required to develop effective nonnative fish control strategies. The research recommendations that follow are drawn from or respond to information needs identified by the GCDAMP, literature reviews, annual nonnative fish workshops, and review of Grand Canyon fish monitoring and research information. Recommendations are listed in order of priority.

Risk Assessment

The formulation of nonnative fish control prescriptions is hindered by the challenge of determining the specific risks nonnative fish pose to native species. For example, is predation, competition, or the combination of both the greatest threat? Many approaches to assess nonnative fish risks to native fish are available, including (1) scoring or ranking various aspects of the fish community, (2) using bioenergetic assessment to evaluate negative interactions, and (3) employing ecosystem approaches, including a variety of biotic and abiotic variables. For example, Johnson and others (2008) developed a bioenergetics model to evaluate the consumptive demand of three nonnative predatory fish on native species in the Yampa River. For this multiyear effort, the authors gathered abundance, growth, and diet composition information for channel catfish, northern pike (*Esox lucius*), and smallmouth bass and determined that channel catfish consumed far fewer native fish than smallmouth bass or northern pike. Valdez and Speas (2009) have evaluated the potential benefits to Grand Canyon fish of the installation of a temperature control device at Glen Canyon Dam. The authors develop a model using temperature degree days to help evaluate the benefits of a temperature control device on fish spawning, incubation, and growth in Grand Canyon. Valdez (2008) also conducted an extensive literature search of the temperature requirements for native and nonnative fish in Grand Canyon and the surrounding area.

Information from the efforts discussed above should be used to develop a bioenergetics or ecosystem modeling effort that evaluates (1) which nonnative fish currently in Grand Canyon has the greatest impact on juvenile humpback chub survivorship; (2) the impact of potential changes in mainstem temperatures associated with a temperature control device, climate change, and dam operations on the bioenergetics or ecosystem relationships of native and nonnative fish; and (3) the impact of temperature on nonnative fish invasion and expansion risk. The goals of this modeling effort will be to identify population expansion or invasion risks to allow managers to control sources of nonnative species and to identify and prescribe a localized control effort that would reduce the greatest nonnative fish related threat to native fish. Assessment of the relative risk posed to native fish by nonnative fish is an important, but complex, component of developing nonnative control strategies. Such an assessment is needed to focus limited resources on those species and areas that are posing the greatest threat as well as to identify where such efforts may be effective. With the completion of this ~~plan~~document reviewing the past and addressing the present, that GCMRC will continue development of a nonnative fish risk assessment.

Identification of the nonnative species that pose the greatest threat to natives and determining when and where negative interactions occur is vital for focused management plans that prioritize removal efforts. This recommendation addresses MO 2.4, SSQ A, B and 5-6; CMIN 2.4.1; RINs 2.4.1, 2.4.3, 2.4.4 and 2.4.6; and EIN 2.4.1 and HBCCP recommendations.

Source Identification

Literature Review

A review of the literature and fish capture information shows that nonnative fish enter into Grand Canyon through tributary inflows; passage through the Glen Canyon Dam turbines or spillway; legal and illegal stocking at access points such as Lees Ferry and Diamond Creek; dispersal from Lake Mead or Lake Powell; and stocking in the lakes, ponds, streams, and reservoirs within the watersheds that feed Grand Canyon. These sources may augment populations of nonnative species already present in Grand Canyon or contribute new species that may have irreversible effects on native species. Evaluation of literature such as historic stocking records, State sport fish stocking plans, nonnative fish captures on tribal lands as well as peer-reviewed literature pertaining to the watershed will assist in identifying sources of nonnative fish into Grand Canyon. Once sources of nonnative fish are determined, management strategies should be developed to minimize the contributions of these sources into Grand Canyon. Identifying the sources of nonnative species will support the long-term sustainability of the control program and even reduce long-term expenditures.

Passage through Dam

Anecdotal information suggests that fish of all life stages can pass through Glen Canyon Dam turbines and survive. Glen Canyon Dam uses Francis turbines to generate power. Survival of small fish for turbine types with large water passages such as Francis turbines is commonly 70 percent or greater, and these turbines are often installed in ‘fish friendly’ applications (Cada, 2001). In April 1984, a threadfin shad was captured 10 miles below Glen Canyon Dam, and on March 7, 2008, a fishing guide at Lees Ferry observed an injured adult channel catfish at the water surface 9 miles below Glen Canyon Dam during the experimental high flow (Dave Foster, Marble Canyon Outfitters, oral commun., 2008). These occurrences indicate at least occasional passage and survival of adult and juvenile fish though Glen Canyon Dam turbines. In June 2006, an adult walleye was captured 1 mile below Glen Canyon Dam, and, in April 2003 and April 2004, an adult and a juvenile smallmouth bass, respectively, were captured within 5 miles of the base of the dam. The presence of these species is likely a result of illegal stocking at Lees Ferry or passage through the dam.

Identification of continued and new sources of nonnative fish into Grand Canyon is recommended. Research should focus on assessing contributions of nonnative fish from dam passage, tributary and watershed inputs. Expanded random electrofishing in the Lees Ferry reach should be employed to better assess nonnative fish in that reach. This recommendation addresses SSQ A; CMIN 2.4.1; RINs 2.4.1, 2.4.3, and 2.4.5; and EIN 2.4 and HBCCP recommendations.

Spawning Area Identification through Isotope and Larval Drift Sampling

Isotopes have been used extensively to determine thermal history and natal origins (when and where young fish are produced) of many fish species (Thorrold and others, 2001; Dufour and others, 2003; Feyrer and others, 2007). Otoliths are collected for isotope analysis as well as age determination studies. Knowledge of spawn timing and location for all fish species in Grand Canyon will help to focus nonnative removal methods and to identify important areas for native fish conservation. Currently, isotope samples are being collected throughout the Grand Canyon as part of the nearshore ecology project.

Isotope information, coupled with larval drift samples, could identify "hot spots" of nonnative fish reproduction and recruitment, thus focusing nonnative fish control strategies. Common carp have a short larval period where they are susceptible to being flushed from spawning habitats by high-flow events. Targeting these downstream drifting larvae using ichthyoplankton nets set during high-flow events could be a cost-effective means of assessing the point sources of carp larvae within river systems. For example, targeted larval sampling was undertaken in catchments within the Murray-Darling Basin for a period of three carp breeding seasons. Data from these collections indicate that carp reproduction does not occur uniformly throughout river systems and that a majority of carp larvae originate from a relatively small number of locations within catchments (Gilligan and others, 2008) Once identified, these localized areas (for example, tributary streams or spring inflows in the mainstem) can be targeted with control options. Larval drift samples can provide data on temporal variability and factors contributing to common carp or other nonnative species spawn timing and success.

Identification of areas important to nonnative fish reproduction through isotope and otolith analysis in combination with larval drift samples is recommended. Information gained from isotope techniques conducted as part of the ongoing nearshore ecology project should be utilized to develop strategies for this approach. Drift sampling downstream of tributary streams should be included in mainstem sampling efforts. This recommendation addresses SSQs A and 1–7; CMIN 2.4.1; and RINs 2.4.1, 2.4.3, and 2.4.5.

Occupancy Modeling for Improving Nonnative Fish Monitoring and Detection

Current monitoring protocols are adequate for detecting changes in brown and rainbow trout relative abundance, and possibly common carp, in the mainstem Colorado River. However, inferring abundance from catch rate information is difficult, often requiring an estimation of capture probability that is not trivial (Tyre and others, 2001; MacKenzie and others, 2006). A model evaluating species presence, or occupancy, can be used as a surrogate to determine the abundance of rare species (MacKenzie and others, 2006; MacKenzie and others, 2004, 2005) and may help to assess abundance of nonnative species that are difficult to capture in Grand Canyon. Occupancy modeling of fish populations has been demonstrated to be important and informative and may be a powerful alternative to capture-intensive methods for analyzing changes in nonnative species relative abundance and distribution. Citing logistical constraints of sampling a site repeatedly, the 2009 Fish Monitoring Protocol Evaluation Panel recommended against developing an occupancy model. However, it is possible that the challenges posed by logistical constraints could be overcome, especially if the nonnative fish monitoring program could be improved. The GCMRC intends to proceed with analyzing the feasibility of developing an occupancy model capable of determining appropriate levels of change in nonnative fish populations in the mainstem Colorado River and the logistics required for implementation of the sampling protocol.

Evaluation of long-term monitoring protocols to detect changes in nonnative fish abundance and distribution using the occupancy framework is recommended. If the sampling requirements associated with protocol are logistically impractical, then sampling tributary inflows and humpback chub aggregations using catch rate indices of multiple gear types should be employed (see Fish PEP Recommendations). This recommendation seeks to improve the ability of scientists to address the majority of GCDAMP nonnative fish related information needs. This recommendation addresses CMIN 2.4.1, RINs 2.4.2 and 2.4.6; and EIN 2.4.1 and HBCCP recommendations.

Small-Bodied and Young-of-Year Nonnative Species

Many small-bodied nonnative fish enter the mainstem from the Little Colorado River (Stone and others, 2007). Several of these species, including YOY common carp, fathead minnows, channel catfish, bullhead species, plains killifish, and green sunfish are rarely found in the mainstem upstream of the confluence area, although they are not unknown from this reach. Cool mainstem temperatures are thought to deter upstream movement of these species (Valdez and Ryel, 1995; Johnstone and Lauretta, 2007). Current mainstem sampling programs may not effectively capture small bodied fish. A program to monitor the abundance of small-bodied warmwater nonnative fish is important for identifying recruitment events and evaluating the effects of warming mainstem temperature, flow regimes and tributary flow events on these species. Use of the slow shocking technique to target small-bodied in the mainstem in proximity of the Little Colorado River and other tributary inflows is recommended. This recommendation is reflected in the nearshore ecology study initiated in 2009. Expansion of this technique to other areas of the Grand Canyon should be explored as well.

Investigating capture and monitoring methods for small-bodied nonnative fish and YOY using the slow-shocking techniques described by Korman and others (2006) is recommended. This recommendation addresses SSQs A and 5-6; CMIN 2.4.1; and RINs 2.4.1, 2.4.3, and 2.4.6 and HBCCP recommendations.

Remote PIT Tag Detectors

Remote detectors for PIT tags have been used in stream systems to determine stream use and large-scale migration patterns and timing for many species. Ibbotson and others (2004) developed a remote system to detect PIT-tagged fish passing a series of antennae. These remote detectors have been modified to determine the directionality of the passing PIT-tagged fish and tag detection probabilities (Connolly and others, 2008). Pinder and others (2007) documented the first evidence of autumn migration of Atlantic salmon (*Salmo salar*) in the United Kingdom using a cross-river PIT tag detector. The use of remote PIT-tag detectors to track migration or residency of nonnative fish in tributary streams of Grand Canyon could help scientists evaluate the effectiveness of the periodic operation of temporary weirs or other removal efforts, among other things. Recommendations for which nonnative fish species and size classes to PIT-tag should be developed through discussions with scientists and managers during annual nonnative fish workshops (See Other Recommendations and Options below). Information gained from tagging of both native and nonnative species would be useful for focusing nonnative fish removal efforts on activities that provide the greatest benefit to natives. For example, detecting PIT-tagged common carp entering the Little Colorado River from the mainstem at a particular time would allow scientists to identify a possible threat to spawning humpback chub and apply removal strategies to take advantage of the period of movement. The GCMRC, in cooperation with the USGS Columbia River Research Lab and Arizona Game and Fish Department, has been testing a remote multiplex PIT-tag detector in the Little Colorado River.

To evaluate nonnative fish movement patterns and identify areas potentially important for spawning, establishment of remote PIT-tag detectors in select tributary streams of Grand Canyon and increasing nonnative fish PIT tagging efforts is recommended. This recommendation addresses SSQs A, B, and 1-7; CMIN 2.4.1; and RINs 2.4.1, 2.4.2, and 2.4.3.

Carp Netting

The Tasmanian Inland Fisheries Service developed a strategy to remove common carp from Lakes Crescent and Sorell, Tasmania, that resulted in the complete eradication of common carp from Lake Crescent in 2009, approximately 15 years after common carp first invaded Lake Crescent (Tasmanian Inland Fisheries Service, 2009). This strategy involved identification and blockage of tributary inflow areas important for spawning and recruitment, implanting radio tags in common carp to assist scientists in targeting aggregations of fish for mechanical removal, and employing mechanical removal techniques, including electrofishing and gill netting. Of the mechanical removal methods employed, gill nets with 6-inch (152 mm) mesh captured 70 percent of the total common carp catch. The 6-inch mesh size was selected to reduce entanglement of smaller native fish.

In Grand Canyon, common carp are rarely captured using electrofishing monitoring protocols in the mainstem or with hoop nets in the Little Colorado River. Large-mesh gill nets may result in greater captures of common carp or other large fish in both the mainstem and in the Little Colorado River. Gill and trammel net mesh sizes historically used in Grand Canyon have generally been between 1 and 3 inches (25 and 76 mm). Large-mesh gill nets should be investigated for use as a monitoring and control method for common carp in the mainstem and the Little Colorado River. Negative impacts of this method on native fish should be carefully considered during testing. (For fish aggregation targeting recommendations, see Sonic Telemetry section below. For identification of spawning areas, see Source Identification section above.) These recommendations address SSQs A and 1-7; CMIN 2.4.1; and RINs 2.4.1, 2.4.3, and 2.4.6 and HBCCP recommendations.

Targeted Manipulation of Dam Releases

Temperature

Olden and Naiman (2009) argue that manipulating flows from dams to provide natural flow regimes (water quantity) only partly addresses maintaining the sustainability of riverine ecosystems. The authors cite water-quality factors, especially temperature, as important drivers for ecosystem processes such as stream productivity and reproductions, growth, distribution, and assemblage of organisms in the system. Cold water pollution is evidenced in Grand Canyon by the distribution of coldwater species closer to Glen Canyon Dam and warmwater species in downstream reaches. Manipulation of temperature may provide a means for benefiting native species and limiting the downstream distribution of rainbow trout to the upper reaches of the river, however, this also has the potential of expanding the distribution, abundance, and increasing the invasion risk of warmwater nonnative fish, some of which are major predators to native fish in the upper Colorado River (Bestgen and others, 2008). Valdez and Speas (2009) predict that warming mainstem temperatures could increase the temperature suitability of a greater area of the mainstem for spawning, incubation, and growth of native species as well as warmwater nonnative species. In April 2007, a scientific panel was convened to review Grand Canyon resource status and to make recommendations for additional experimentation in a long-term experimental plan (Grand Canyon Monitoring and Research Center, 2008). This panel was advised that implementation of a temperature control device on Glen Canyon Dam was being seriously considered. The panel, like review panels before it (Mueller and others, 1999; Garrett and others, 2003), recognized the potential risks of releasing only warmer water from Lake Powell. Therefore, the 2007 panel recommended the design, construction, and implementation of a temperature control device on Glen Canyon Dam that had the capacity to release both warm and cold water from Lake Powell. The ability to release both warm and cold water would likely increase the ability of scientists and managers to address risks posed by a variety of nonnative fish, and so would be considered a dramatic increase in the capacity for nonnative fish control to benefit native fish (Grand Canyon Monitoring and Research Center, 2008). Implementation of a broad range temperature control device is recommended and will require careful consideration of the potential benefits of warm water to both native and nonnative fish.

Flow Regimes

Manipulation of flow regimes from dams has been identified as a potentially powerful tool for managing native and nonnative fish species. Brown and Ford (2002) determined that flow regime was important to the reproductive success of both native and nonnative fish species in a regulated river in California. The authors determined that the flow patterns from the previous year differentially affected the reproductive success of native and nonnative species and, thus, the resulting community in the following winter and spring. Jennings and Philipp (1994) determined that during 2 years that were characterized by low, relatively stable flow, longear sunfish (*Lepomis megalotis*) nest failures were attributable to biotic interactions, whereas during a 2-year period with more variable flow, most brood losses occurred during floods. The authors concluded that flooding led to nest desertion and loss of offspring regardless of nest location. Lukas and Orth (1995) examined the influences of habitat, temperature, stream discharge, and timing of spawning on the nesting success of smallmouth bass in a Virginia stream. High flow (>10 m^3/s) disrupted spawning on five occasions and was responsible for most nest failures (85 percent). The authors noted increased water velocity at nest sites with increased stream discharge as the most likely cause of nest failures. The temporal pattern of stream flow fluctuation appeared to be the most important abiotic factor in determining nesting success or failure for smallmouth bass. Simonson and Swenson (1990) determined that young smallmouth bass that had recently emerged from nest gravel (7 to 9 mm) were displaced both from field nest sites and laboratory flume nest sites at velocities of 8 mm/s. Smallmouth bass nests in areas of higher velocities (15 mm/s) failed to produce young. However, caution is warranted because these studies did not directly measure the fate of displaced young fish. In the Green River, Bestgen and others (2007) linked recruitment failure of smallmouth bass in 2004 with captures of newly hatched individuals in drift samples during conditions of increased turbidity and flow. In a 10-year study of a California stream, Strange and others (1993) determined that fish community structure changed under the influence of storm-induced high-flow events that negatively affected fish recruitment. Relative abundance was altered as a result of pre-recruitment stream discharges, differentially influencing year-class strength among species with contrasting life histories. In all of these studies, knowledge of the specific life history associated with spawning of each species was necessary to develop studies to identify the effects of flow regimes on recruitment.

Modification of the fish community in Grand Canyon has been attempted using flow manipulation with varying goals and responses. Authors of the HBCCP summarize the results and potential use of floods in Grand Canyon as follows:

> Floods have, for some time, been identified as a potential means to disadvantage nonnative fishes and thereby advantage native fishes (Meffe 1984). Likewise dam operations could be utilized to disadvantage nonnative fishes via artificial floods or other flows from displacement due to flooding, stranding, or altering spawning and rearing habitats. And yet, the 1996 Glen Canyon Dam beach habitat building flow appeared to have only short-term effects on the densities of some nonnative fishes (primarily small-bodied forms like plains killifish and fathead minnow; Hoffnagle et al. 1999; Valdez et al. 1999), perhaps because at 45,000 cfs, the flow was still less than the pre-dam one-year return interval flood of 50,000 cfs (Hoffnagle et al. 1999, Topping et al. 2003). From 2003-2005, releases from Glen Canyon Dam included "experimental fluctuating flows", high fluctuating releases of 5,000-20,000 cfs per day from January-March, to test their capability to reduce the survival rate of young rainbow trout to reduce the size of the Lees Ferry trout population. These flows had little effect on incubation mortality and consequently adult population size. Additionally, reductions in early life stages appeared to be offset by compensatory survival at larger life stages (Korman et al. 2005). Korman et al. 2005 did note however that because young-of-year rainbow trout generally remain at the daily minimum flow elevation in Lees Ferry, and because September flow reductions during the study resulted in density reductions documented in Glen Canyon, as well as substantial literature on stranding impacts to young trout, a 'stranding' flow operation from Glen Canyon Dam targeted at reducing young-of-year rainbow trout recruitment could be very effective.

Full development of targeted flow and temperature manipulations for Grand Canyon will require a comprehensive review of native and nonnative life history. Prescribing a flow and temperature treatment to disadvantage nonnative fish recruitment to benefit native fish is recommended. A temperature control device is recommended to support development of a broad range of treatments to benefit native fish. It will be particularly important to continue monitoring native and nonnative fish along with implementation of any flow and temperature manipulations to document and respond to any species responses to experimental flows. This recommendation addresses SSQs A and RINs 2.4.1, 2.4.2, and EIN 2.4.1 and HBCCP recommendations.

Pheromone and Sensory Attractants

In a review of the potential use of pheromones, Sorensen and Stacy (2004) concluded that use of pheromone baits to increase trapping efficiency would be an important tool to suppress reproductive potential of adult common carp. Sorensen, from the University of Minnesota, is developing pheromone attractants specifically for common carp to assist in control efforts. Sorensen's research represents a collaborative effort with the New South Wales Department of Primary Industries, the South Australian Research and Development Institute (SARDI), and the Invasive Animals Cooperative Research Centre in Australia. Sorensen presented the results of his study at an Annual Invasive Animals Cooperative Research Centre breakthrough lecture series for which the University of Canberra issued a press release in June 2007 (Curtis, 2007).

According to the press release, Sorensen's research has identified a male-derived pheromone that may have "multiple uses in attracting, diverting, and removing common carp by controlling the responses the female common carp has towards males." Sorensen presented the concept of "hotspots," locations where common carp spawning occurs en masse, which are common to most systems. These hotspots are thought to result from environmental and pheromonal cues. This research suggests environmental and pheromonal cues could stimulate common carp to migrate and concentrate in a particular area where they could then be physically removed.

Sorensen expected to have a product available in the near future, and the Invasive Animals Cooperative Research Centre could not comment on a product availability timeline (W. Fulton, Invasive Animals Cooperative Research Centre, written commun., 2007). Pending authorization for widespread use, this product could be used in the future to increase common carp captures in localized areas within Grand Canyon. Identification of hot spots and development of capture methods to target these areas will be required.

Pheromone attractants have also been documented to attract channel catfish (Timms and Kleerkoper, 1972). The authors demonstrate that sexually mature male channel catfish are attracted by a pheromone released by ripe females. This was measured by the tendency of male channel catfish to move toward and remain within close proximity to a point source release of the female pheromone. A female pheromone has also been identified as an attractant to black bullhead (*Ameiurus melas*) (Wallace, 1970 and Kendle, 1970).

Young and others (2003) observed increases in brook trout captures in hoop nets seeded with male brook trout in reproductive condition. Hoop nets were seeded with ripe male and female brook trout. Those nets seeded with ripe males resulted in disproportionately higher catch rates of ripe male. Nets seeded with ripe female brook trout did not result in catch rate differences. Seeding hoopnets with ripe trout may result in increased catch rates of fish in reproductive condition and could be applied to mainstem or tributary trout removal in Grand Canyon.

Use of pheromone attractant methods such as placing ripe female fish or ovaries in catfish nets could potentially increase capture rates of bullhead species and channel catfish. This method should be combined with other bait types on an experimental basis to test the relative effectiveness of each bait type or combinations of bait types. This experiment should be conducted in the Little Colorado River and the confluence area where channel catfish and bullhead species captures are more common. This recommendation addresses SSQs A and 1-7; CMIN 2.4.1; and RINs 2.4.1, 2.4.3, and 2.4.6 and HBCCP recommendations. (See Channel Catfish and Bullhead Species Removal in the Little Colorado River and Confluence Area below).

Sonic Telemetry

Telemetry has been used in many aquatic systems to identify spawning areas, feeding areas, migration patterns, site fidelity, and environmental factors affecting fish movement (Clements and others, 2005; Childs and others, 2008; Humston and others, 2005; Mallen-Cooper and others, 1995; Tasmanian Inland Fisheries Service, 2009). In Australia, "Judas" fish, or radio-tagged fish that reveal the locations of fish groups by gravitating toward their own species aggregations, are used to help understand fish habitat preference and behavior and increase the effectiveness of mechanical and chemical control (Lintermans and Raadik, 2003, Diggle and others, 2004; Tasmanian Inland Fisheries Service, 2009). Telemetry can also be used to compare and evaluate native and nonnative species spatial and temporal overlap (Jackson and others, 2001).

A sonic-tag study was implemented in Grand Canyon during the 2008 high-flow experiment (HFE) to determine the effects of the HFE on rainbow trout movement (Hilwig and Makinster, in press). Concern was raised that rainbow trout could displace from Lees Ferry into areas unavailable to anglers and important for humpback chub. Ninety-four rainbow trout ranging in size from 157 to 409 mm total length (TL) were tagged during the study. Average movement of located, tagged rainbow trout was similar for all size classes and both sexes before or after the

HFE. A total of 3 of 94 acoustic tags (3 percent) were detected by a remote receiver located 6 miles downstream of Lees Ferry. The greatest documented movement of a tagged trout was more than 18.1 miles downstream, which occurred before the HFE. The greatest upstream movement of a tagged trout was 6.4 miles, which also occurred before the HFE. Individual fish movement was highly variable and did not correlate to the occurrence of the HFE, length, or sex. The average movement of tagged rainbow trout, which was 305 to 405 mm, tended to be less variable after the HFE. The 2008 HFE did not appear to cause displacement below Lees Ferry of the majority of tagged rainbow trout. Specific location of individual fish could be accomplished, if the density of tags at large was reduced or tagged fish were subsampled. Sonic tags allowed for the determination of movement patterns and individual fish locations (habitat identification) of fish larger than 157 mm in Grand Canyon.

Sonic telemetry should be used in Grand Canyon to identify areas of importance to native and nonnative fish, so that efficient control strategies can be developed. Sonic-tagged fish can provide information about migration cues, impacts of dam releases or water-quality conditions on fish distribution, species overlap, and tributary and other habitat usage. For example, sonic tagging common carp in the Little Colorado River may allow scientists to identify aggregations of common carp, determine conditions in which aggregations occur, and gain insight into common carp behavior. This information would assist scientists in identifying potential impacts of common carp on humpback chub and formulating removal strategies. Studies of surgical implantation methods and long-term survivorship should be conducted to assist in the evaluation of the results. Surgical implantation of sonic tags into adult nonnative fish such as walleye and smallmouth bass captured in the Lees Ferry Reach is also recommended. These fish could be tracked to determine the fate of nonnative fish and potential spawning locations and activity.

Use of sonic telemetry to identify areas of importance to native and nonnative fish, evaluate spatial and temporal movement patterns and track Judas fish is recommended. This recommendation addresses SSQs A, 1-7, and 5-6; CMIN 2.4.1; RINs 2.4.1, 2.4.3, and 2.4.5; and EIN 2.4.1.

Experimental Stream Studies

Determining the interactive mechanisms by which nonnative fish affect native fish is difficult in a field setting. Laboratory tests are often used to evaluate hypotheses in controlled situations. Although laboratory settings do not exactly emulate field conditions, test results can be useful in evaluating these mechanisms and devising management strategies to limit potentially negative interactions. The GCMRC recommends study of the impact of nonnative fish on juvenile humpback chub in an experimental stream. Growth, condition, and mortality of juvenile humpback chub can be easily measured in an experimental stream setting. Several nonnative fish species and size classes can be tested in combination with various water temperatures to evaluate the conditions that pose the greatest risk to juvenile humpback chub. This study should provide insight into how juvenile humpback chub survivorship is affected by nonnative fish and temperature in Grand Canyon.

Investigation of negative interactions among native and nonnative fish in an experimental stream setting is recommended. This recommendation addresses SSQs A, B, and 5-6; CMIN 2.4.1; and RINs 2.4.1, 2.4.3, and 2.4.4 and HBCCP recommendations.

Williams' Carp Cage

The Williams' Carp Cage was developed by researchers from the Arthur Rylah Institute for Environmental Research and Goulburn Murray Water weir keepers for use in the Murray-Darling

Basin, Australia. Stewart and others (2006), the developers of the trap, describe it as a key tool within broader common carp control initiatives and river rehabilitation actions, providing a solid low-cost technique for mechanical control efforts. The trap prevents nonnative fish from using fishways designed to facilitate native fish passage through weir structures. Researchers observed that common carp tended to jump upstream when they were captured in the standard fishway monitoring traps. The traps were modified to separate jumping common carp from non-jumping native fish. The fishway is a cement-walled vertical canal, approximately 200 m long and 2 m wide, and usually operates at 1 m water depth. During the testing, the majority (88 percent; 370 individuals) of adult (244 to 710 mm) common carp that entered the fishway jumped into the confinement area. Since the fishway became operational in 1991, several thousand common carp have been trapped and manually removed each year (Mallen-Cooper, 1999). Since 2001, however, less than 500 common carp are now removed annually, which corresponds to a more general trend of population decline of the species in the mid-Murray River (Nicol and others, 2004). Researchers are currently testing a modified version of the trap in wetland areas and free-standing applications with mixed results (W. Fulton, Invasive Animals Cooperative Research Centre, written commun., 2007).

Application of Williams' Carp Cage concept in the Little Colorado River may be possible but limited to areas where the river narrows or in areas where common carp are observed in large schools. Creative thought and prototype testing will assist in evaluating feasible application and value of this method.

Nonnative Fish Research for Future Consideration

Daughterless Technology

In 2003, a collaborative project between the Australian Murray-Darling Basin Commission, the Commonwealth Scientific and Industrial Research Organisation's Marine Research, and the Pest Animal Control Cooperative Research Centre was launched to develop genetic methods for common carp control. Researchers have targeted a gene that allows embryos to develop into normal female fish. Fish that no longer express this gene, termed the daughterless gene, can only produce male offspring. Researchers have successfully produced neomales, or genetic females that are functional males, and are now spawning the neomales to determine whether the daughterless gene will be inherited. Skewing sex ratios to favor males in conjunction with other management practices may allow for widespread common carp reduction. However, this would require swamping existing common carp populations with genetically modified daughterless common carp. Researchers estimate that a successful daughterless carp approach would require 40 to 50 yr to implement because of the long lifespan of common carp and should be used in conjunction with other short-term control techniques. Authorization for the widespread release of the carriers is currently being perused (Invasive Animals Cooperative Research Centre, 2006).

Infectious Agents

Koi herpes virus (KHV) is a viral disease that is highly contagious to common carp, causing significant morbidity (sickness or disease) and mortality (Hedrick and others, 2000). The virus, which attacks gills and other vital organs and often initiates secondary infections, eventually kills its host. The Washington Animal Disease Diagnostic Laboratory at Washington State University determined that KHV was the cause of death for thousands of common carp in Lakes Mohave and Havasu in the spring and summer of 2009. Researchers at the Commonwealth Scientific and Industrial Research Organisation's Livestock Industries' Australian Animal Health Laboratory, along with the Department of Primary Industries Victoria, are investigating KHV as a means of controlling common carp. Ongoing research suggests that KHV has a very limited host range, infecting only common carp (Commonwealth Scientific and Industrial Research Organisation, 2006). Because of this host specificity, KHV is being developed as a biological control agent as part of a larger pest-fish control program under the Invasive Animals Cooperative Research Centre and the Murray-Darling Basin Commission.

Other Recommendations and Options

Annual Nonnative Fish Workshop

This ~~plan~~document advocates hosting an annual workshop for managers, scientists, and stakeholders to discuss nonnative fish collections in Grand Canyon, new capture techniques, pilot project results, management issues, long-term planning, and priorities. The Upper Colorado River Endangered Fish Recovery Program Convening has successfully used annual workshops to share information and improve planning activities. Recent nonnative fish workshops were conducted by the GCMRC in December 2005, October 2007, and December 2008. Workshop participants should include cooperators, agency managers, GCDAMP stakeholders, and topic experts. Information reviewed should include annual monitoring results and limitations and changes in distribution and length frequency (figs. 7 and 8 for examples of historical data and Response Triggers section below). Data in figures 7 and 8 represent common carp catches during a variety of projects, sampling procedures, and sampling gears and should be interpreted carefully. It is ~~recommended~~ emphasized that this gathering should take place annually and serve as the venue for prioritizing the recommendations and options presented in this ~~plan~~document. Changes in control activities should be carefully evaluated with close attention to data from annual monitoring and research programs. Changes in priorities will be evaluated before implementation and will be reviewed with scientists and managers during annual nonnative fish workshops. The GCDAMP would also review proposed changes. With repeated implementation, it is anticipated that this annual meeting will contribute to the continued evaluation of processes for implementing priority tasks. It is anticipated that the Grand Canyon nonnative fish community will always be changing. The species present their population sizes, distributions, and spawning effectiveness, among other factors, are most likely variable from year to year. An annual nonnative meeting will help scientists and managers track these variables, amend work plans accordingly, and respond appropriately.

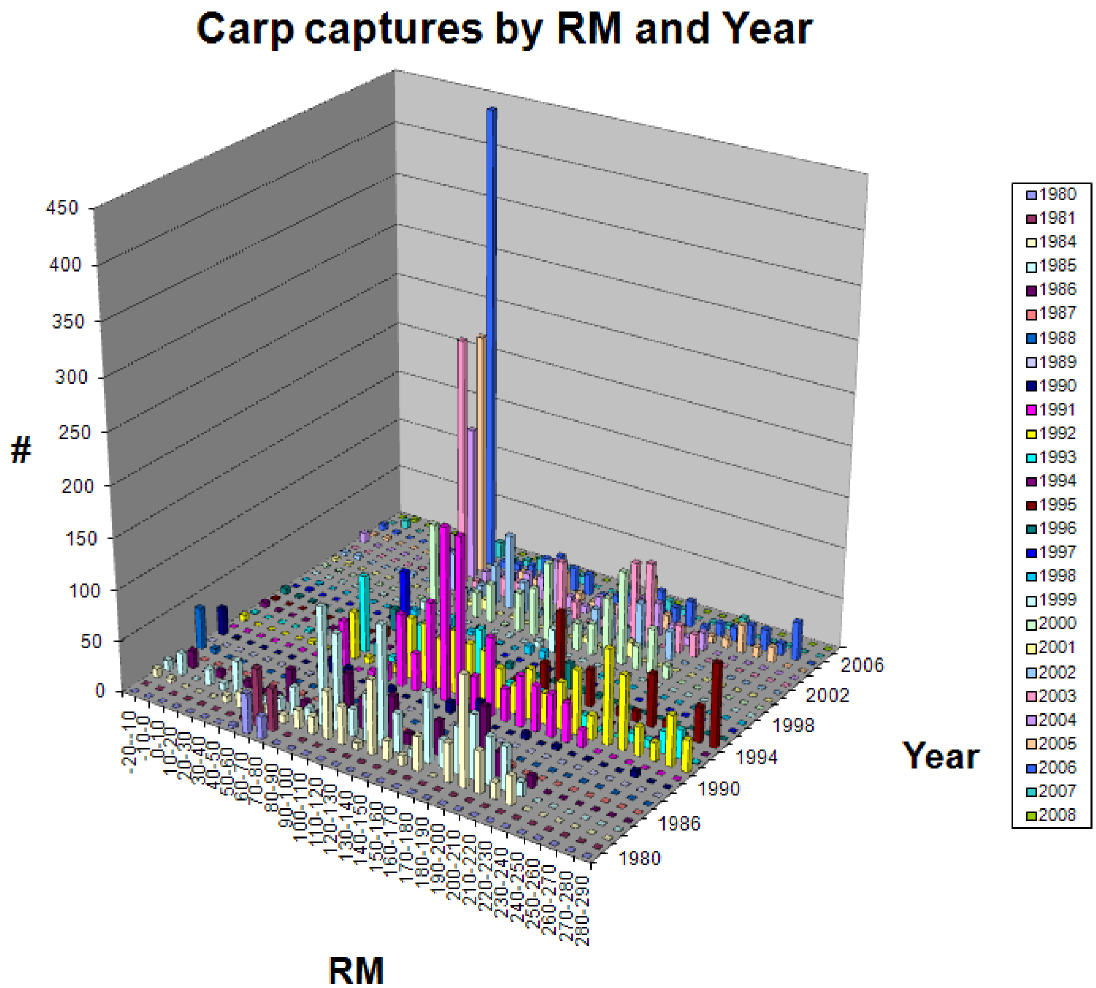


Figure 7. The number of common carp captured in the mainstem of Grand Canyon summed for all gear types. Carp are most commonly captured near the confluence of the Little Colorado River (RM~60) and downstream of RM 60 throughout the Colorado River. The peak in carp captures near RM 60 is likely the result of increased sampling intensity from 2003 to 2006 near the Little Colorado River. Represents only data contained in the Grand Canyon Monitoring and Research Center database for electrofishing, hoop netting, seining, angling, and trammel netting combined as of December 2008. Data represents common carp catches during a variety of projects, sampling procedures, and sampling gears and should be interpreted carefully.

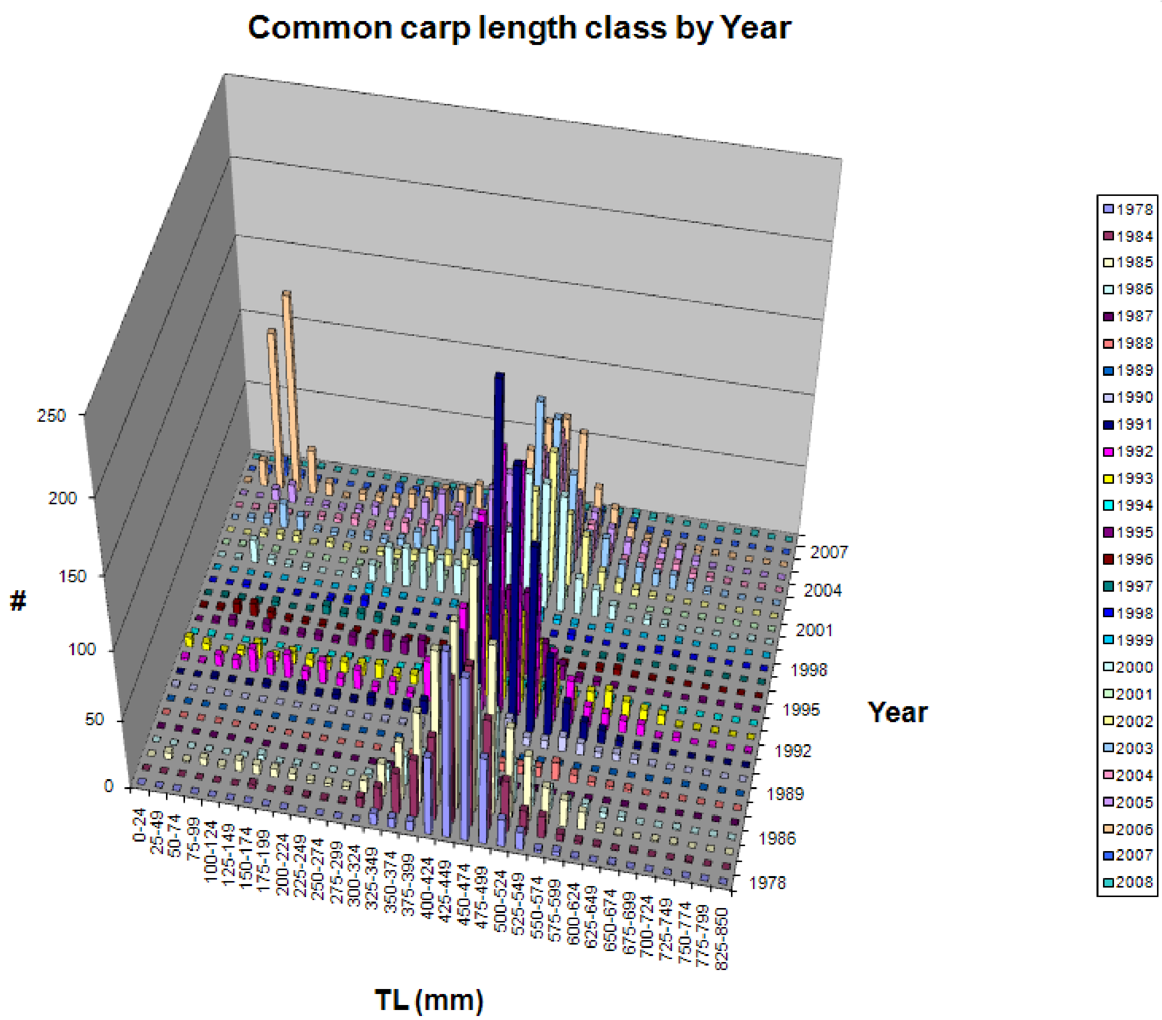


Figure 8. The length classes of all carp captured over time in the mainstem of the Colorado River in Grand Canyon. Adults are consistently captured in the mainstem, but juveniles appear to have been captured more frequently in 2006. This may be a result of a flow event through the Little Colorado River (LCR) and suggests that carp are likely reproducing in the LCR (see LCR Carp captures below) and this cohort may have remained in the mainstem in proximity to the LCR or warmer mainstem temperatures leading to mainstem spawning of common carp. Represents only data contained in the Grand Canyon Monitoring and Research Center database for electrofishing, hoop netting, seining, angling, and trammel netting combined as of December 2008. Data represents common carp catches during a variety of projects, sampling procedures, and sampling gears and should be interpreted carefully.

Prevention and Public Outreach

Currently, nonnative species detected in Grand Canyon represent only a fraction of the community that could establish itself in the Colorado River. Many nonnative species not yet established in Grand Canyon have caused population declines and even extinctions in the upper Colorado River Basin and other systems (Minckley and Deacon, 1991). The nonnative fish community established in Grand Canyon does not represent the full potential assemblage of nonnative fish that have established and have had major impact on native fish in other areas of the Colorado River Basin, including gizzard shad (*Dorosoma cepedianum*), white sucker (*Catostomus commersoni*), northern pike (*Esox lucius*), smallmouth bass, and blue tilapia (*Oreochromis aurea*).

Preventing new invasions of nonnative species is the least expensive and most effective way to control the negative effects of nonnative species when compared to the cost of control projects after invasions occur (Leung and others, 2002). Increased public outreach activities, as recommended by the Nonnative Fish Control Ad Hoc Committee in 2002, are important to successful management of nonnative fish in Grand Canyon (management objective 2.4). Public outreach can increase public understanding of the effects of nonnative fish on native fish and the justification for nonnative fish control efforts. Public outreach also provides an opportunity to inform people about the effects of actions such as illegal stocking and potentially deter such practices.

Two nonnative fish projects conducted in Grand Canyon have incorporated public outreach. First, informational pamphlets were distributed locally and posted at Lees Ferry as part of the mechanical removal project near the Little Colorado River. Project personnel also visited river camps in the study area to address concerns and answer questions. During the trout removal project in Bright Angel Creek undertaken by GCNP, a wide range of outreach activities were undertaken, including (1) posting and distributing informational posters, (2) informing park rangers of project details so that they could answer visitor questions, (3) including informational inserts with backcountry permit packets, (4) participating in the “Talk to a Ranger” program at Phantom Ranch, and (5) encouraging visitors to provide volunteer support to weir operation (for example, recording data, carrying buckets). Finally, project staff conducted a brown bag lunch program for Grand Canyon National Park employees describing the project and initial results. Results have also been presented at professional society meetings and submitted to “Nature Notes,” a Grand Canyon National Park publication. The U.S. Fish and Wildlife Service also worked with GCNP outreach staff to develop Web site materials and updates for interested parties. The outreach effort related to trout removal from Bright Angel Creek not only provides a foundation for future efforts to describe nonnative fish issues in Grand Canyon, but also served to reduce potential negative public perceptions of the project. An example of public outreach material associated with the Bright Angel Creek weir is provided in appendix B. Development and production of the public outreach methods and materials should be coordinated among the GCDAMP Public Outreach Ad Hoc Group and professional outreach staff of the National Park Service, Bureau of Reclamation, and U.S. Geologic Survey.

Topics recommended for public outreach:

- Importance of native fish conservation in Grand Canyon
- Negative effects of nonnative species on conservation efforts for native fish
- Purpose and description of nonnative fish removal programs
- Effects of illegal stocking of nonnative fish, associated fines, and witness reporting information

Reporting Procedures

Several entities conduct scientific fish sampling in Colorado River Ecosystem and its watersheds, including National Park Service, Arizona Game and Fish, Utah Division of Wildlife Resources, Colorado Division of Wildlife, U.S. Geological Survey, U.S. Fish and Wildlife Service, Tribal entities, and other scientists and managers. Often there is little or no immediate exchange of information among these entities and extended delay before data are error checked and entered into a common database. The ability to detect nonnative fish occurrences in a timely manner is important to formulating rapid management responses. A formalized reporting system to document nonnative species captures or observations is recommended for distribution to all professional entities sampling fish in Grand Canyon. This information will be used to augment annual tracking of changes in nonnative species abundance and distribution. The existing GCMRC fish database will be expanded to accommodate these additional capture data.

Development of a formal nonnative fish capture reporting system is recommended. This recommendation addresses CMIN 2.4.1.

Contingency Planning ~~Recommendations~~

Ideally, invasions of new nonnative species in Grand Canyon or increases in abundance and distribution of species already present would be detected in a timely manner, so localized reduction efforts could be applied to a problem species and area before extensive population growth occurs. For example, ideal control efforts would involve detecting the presence of adult nonnative fish before they reproduce and targeting adult fish for removal with a capture method that has proven effective. This scenario requires frequent monitoring and implementing effective capture methods that are immediately available. Because of the limits of current monitoring methods, expansions and invasions can go undetected until a nonnative species reach a relatively high abundance, at which point removal efforts to offset recruitment and immigration of the nonnative species would require additional effort and are likely to be less effective. A monitoring program that could detect the presence of all the species and life-history stages that may expand within or invade Grand Canyon is infeasible. The success of nonnative species control is closely tied to early detection techniques and effective capture methods, neither of which is optimally available at present.

Determining which nonnative fish poses the greatest risk to native fish is complicated by the uncertainty about the possible expansion of existing nonnative populations into areas important for natives, what nonnative fish species may invade Grand Canyon in the future, and how future environmental conditions (for example, drought-induced warming and tributary flooding) may benefit nonnative species. The nonnative fish species targeted for removal on an annual basis may change in a very short time frame as new sampling information is gathered and threats identified. The following ~~recommendations~~approaches were developed to identify and address emerging threats and assist scientists in defining triggers to initiate immediate nonnative fish control campaigns and strategies to gain insight into efficient removal strategies when none may have been proven in Grand Canyon.

Response Triggers

Invasive species populations can expand at exponential upon entry into new systems. Exponential expansion can occur after the initial introduction of a few individuals and during range expansion of an established invasive species (Kolar and Lodge, 2002). Successful invasion is usually characterized by the movement of adult individuals into new areas, followed by a strong pulse of recruitment. This pattern shows that detection of both young and adult nonnative species is important when evaluating triggers to initiate reduction programs. It is difficult to use catch-rate changes associated with long-term monitoring data to define triggers because catch rates can be influenced by different factors and it is difficult to extrapolate abundance from them. Information to make scientifically credible determinations is limited and, thus, requires the best professional judgment to formulate recommendations based on current conditions. Evaluation of multiple parameters will be required to assess potential nonnative fish expansion and the need for action on an individual species basis. Annual nonnative fish management workshops should be the venue for evaluating triggers that would initiate nonnative fish control, because during the annual workshop scientists will present their most recent findings related to nonnative fish monitoring and research. Up-to-date monitoring and research findings should form the basis of discussions regarding whether or not to initiate nonnative fish control actions. The following indices are recommended for evaluating response triggers, which are keys to effective contingency planning.

Catch Rate Inferences

Long-term monitoring protocols are likely adequate to detect large annual changes (that is, >100 percent) in catch rates of rainbow trout, brown trout, and potentially common carp. Furthermore, continued evaluation of multiyear catch rate data associated with all nonnative fish in each reach can help to identify and track potential problems. Application of a standardized trigger for a focused removal program is difficult because of different relative species abundance in reaches. Thus, a proportional criterion for applying a trigger (for example, a 20 percent increase in catch rate of a rare species) may capture a nonnative species expansion issue; however, application of this same trigger to a locally abundant nonnative species may be misinterpreted (for example, when a 20 percent increase is contained within the variance of the catch rate). Thus, close tracking of catch rate information from multiple gear types, multiyear samples, and other factors mentioned below will be used to evaluate potential nonnative fish expansions on a species-by-species basis.

Changes in Distribution

Investigation of species distribution is a useful tool for evaluating species range expansions, especially in relation to warming river temperatures. Monitoring data will provide the baseline from which changes in distribution will be evaluated. The degree of overlap with areas important to native fish will also be evaluated. Monitoring information should be augmented with catch information from other fish-sampling projects.

Changes in Species Composition

Changes in the relative abundance of nonnative fish species will be used to evaluate potential expansions of nonnative fish species in each reach. Again, it is difficult to apply a single threshold, such as a 20 percent increase in proportion of a species captured, given differences in catch rates and abundance. Changes in composition for each species will be evaluated using the same spatial designations used to evaluate changes in distribution.

Changes in Length Composition

Analysis of changes in length composition over time will provide insight into changes in population structure in each reach, such as increased juvenile or adult abundance. Changes in length composition for each species will be evaluated using the same spatial designations used to evaluate changes in distribution. For example, if the electrofishing catch rate of a large-bodied nonnative species increases in reach 2, young fish are observed for the first time in this reach, and the number of young fish substantially increases in proportion to the total species capture in seining samples, a population expansion would be indicated by the data.

Nonnative Fish Control Contingency Fund

Reducing nonnative fish abundance in large river systems can be expensive. The GCMRC recommends establishing a nonnative fish control contingency fund dedicated to nonnative fish control in the event that a new species invades the system or existing populations expand into areas important for native fish conservation. This fund should be developed so that ongoing fish monitoring and research activities in Grand Canyon are maintained because these activities provide the basis for evaluating the native and nonnative fish community in Grand Canyon. Therefore, it is critical to maintain these functions so that the collected data can be used to determine whether nonnative control is needed.

The costs of nonnative control efforts will vary depending on many factors, including species targeted and gear required, the location of the removal, the goals of a specific project, and other factors. The rate of immigration into a removal reach and any local reproduction will also affect the level of control required. For comparison, the 4-year long effort to reduce rainbow trout and other nonnative fish in the Little Colorado River reach of the Colorado River cost approximately $2 million. The techniques from that project were re-applied in 2009 at a cost of approximately $150,000 for a single, six-pass trip. Current estimates suggest that if rainbow trout immigration into the removal reach continues as it did in 2003–06, and population estimates are accurate, then two annual removal trips to this reach would be required to maintain the population of rainbow trout at 10 to 20 percent of the January 2003 levels. In order to conduct two trips comparable to the 2009 effort in any year where nonnative species control is required, it is recommended that a nonnative control contingency fund be established with GCDAMP contributions of $300,000 annually, with the total not to exceed $900,000 over 3 years. This contingency fund should be used as the funding source for controlling any nonnative species in Grand Canyon determined to be posing a high risk to humpback chub.

Responding to Perceived Nonnative Fish Threat

In the event that nonnative fish reduction triggers—to be reviewed annually by the scientists and managers participating in the annual nonnative fish workshop proposed by this ~~plan~~document—are met, immediate reduction efforts should be initiated. However, proven reduction methods are not available for many nonnative species in Grand Canyon, which necessitates the use of gears with moderate, poor, or unknown capture efficiencies while new methods are being evaluated. Combining several capture methods with sonic tracking and targeting problem areas with the gears that are most likely to capture target species offers the greatest chance for temporary reduction of nonnative species while new, more sustainable methods are being developed for this program and others around the world.

The following contingency statements address nonnative fish issues that may arise in Grand Canyon in the near future and recommended responses to these threats:

- If smallmouth bass, green sunfish, or walleye captures in the Lees Ferry area demonstrate a population expansion, then an intensive electrofishing, angling, and netting campaign to capture and remove these species should be initiated immediately.
- If smallmouth bass, green sunfish, or walleye captures in the Lees Ferry area demonstrate a population expansion, then implantation of sonic tags in suitable individuals should be initiated immediately, concurrent with the removal efforts cited above, to determine extent of the expansion and potential removal strategies.
- If smallmouth bass or green sunfish in the Lees Ferry area demonstrate a population expansion, then development and implementation of flow manipulations to disadvantage these species should be initiated immediately, concurrent with the removal efforts cited above.
- If channel catfish or black bullhead captures in the Little Colorado River, and/or the mainstem Colorado River near the mouth of the Little Colorado River, demonstrate a population

expansion, then an intensive netting and angling campaign to capture and remove these species should be initiated immediately. This effort should be weighed carefully, along with the benefit and risk of releasing PIT- or sonic-tagged individuals.

- If channel catfish or black bullhead captures in the Little Colorado River or the mainstem continue to increase, then efforts to implant sonic tags in suitable individuals should be initiated immediately to determine extent of the expansion and potential removal strategies, concurrent with the removal efforts cited above.
- If rainbow trout attain abundances greater than 20 percent of January 2003 abundance estimates, then mechanical removal should be reinitiated to reduce the population size to approximately 10% of the estimated January 2003 abundance.

Recommendation and Options Summary

The following recommendations and options are listed in priority order by category.

Monitoring Recommendations

- Expand current mainstem monitoring, focusing initially on areas in proximity to humpback chub aggregations and tributary inflows
- Implement an early detection protocol and nonnative fish monitoring in Lees Ferry
- Implement long-term monitoring program in tributaries and confluence areas of the Grand Canyon

Removal Options

- Maintain trout abundance in the Little Colorado River reach at approximately 10 to 20 percent of January 2003 rainbow trout abundance (approximately 600 to 1,200 rainbow trout)
- Continue to remove trout in Shinumo Creek using backpack electrofishing in combination with other methods such as weirs and angling to support translocation efforts
- Continue to remove trout in Bright Angel Creek using a weir, backpack electrofishing and other methods
- Pilot test catfish nets and stink cheese to remove and monitor channel catfish and bullhead species in the Little Colorado River and the confluence area
- Undertake chemical renovation and barrier construction in tributary streams identified as sources of nonnative fish into Grand Canyon

Research Recommendations

- Develop a model to identify the nonnative species posing the greatest risk to humpback chub
- Identify sources of juvenile and adult nonnative fish into the mainstem such as recruitment locations, tributary inflows, dam passage, and illegal stocking
- Develop occupancy model for improvement of long-term nonnative fish monitoring, evaluation of nonnative fish population expansion or contraction, and development of early detection protocols

- Undertake a small-bodied nonnative fish and YOY capture and monitoring study using slow-shocking techniques (nearshore ecology) throughout the mainstem
- Continue efforts to develop remote PIT tag detection technology for application to nonnative fish and tributary streams
- Use large mesh gill nets to target common carp in the Little Colorado River and the confluence area
- Develop flow manipulations of both water quantity (experimental flows) and temperature (a temperature control device) to disadvantage nonnative species while benefiting natives
- Use pheromone and sensory attractants to increase capture efficiencies for channel catfish and bullhead species
- Initiate sonic telemetry studies for native and nonnative fish to compare and identify spatial and temporal movement patterns, tributary use, and spawning areas
- Undertake experimental stream tests to investigate mechanisms by which nonnative fish negatively affect juvenile humpback chub
- Modify the Williams' Carp Cage to capture common carp in tributaries
- Consider stocking daughterless carp and introducing infectious agents that target nonnative fish species in the future for long-term nonnative fish control

Other Recommendations and Options

- Conduct an annual nonnative fish workshop with cooperators and other nonnative fish experts to review current information and to help prioritize efforts
- Undertake public outreach activities specifically for nonnative fish management issues with attention to preventative measures such as deterring illegal stocking
- Develop a formalized reporting procedure for nonnative fish captured and observed by professional entities performing sampling within Grand Canyon

Contingency Planning

- Define agency roles and develop rapid response plans to address nonnative fish expansions or new invasions
- Evaluate response triggers to initiate control measures of nonnative fish abundance from changes in catch rate, distribution, species composition, and length frequencies (reviewed at annual nonnative meeting)
- Apply current capture methods used in Grand Canyon while more effective methods are being developed
- Implant sonic tags in nonnative fish to help evaluate dispersal, potential spawning activities, and other factors
- Establish a nonnative fish contingency fund for ongoing monitoring and research activities

Implementation Strategies for Monitoring, Research, and Control

Based on the guidance provided by the GCDAMP, the overarching intention of nonnative fish management planning is to reduce the threats posed to native fishes by nonnative fish species. A multifaceted plan is required to effectively reduce the varied and multiple threats posed to Grand Canyon native fish by the nonnative fish. Table 4 identifies a strategic approach to address nonnative fish issues in Grand Canyon and the recommendations -and options presented by this document for pursuing these strategies.

Table 4. Summary of the strategic approach to addressing nonnative fish issues in Grand Canyon and the monitoring and research recommendations and control options related to each strategy presented in this document.

Strategy	Recommended actions
Develop a risk assessment to identify the nonnative fish species that poses the greatest risk to native species. This includes identification of particular size classes of nonnative fish that pose the greatest threat to native fish populations. Ideally, this threat assessment would identify the nonnative fish posing the greatest risk in space and time to native fish.	1. Develop risk assessment 2. Continue testing of remote PIT-tag reader 3. Implement sonic telemetry 4. Improve monitoring 5. Continue experimental stream study
Identify sources of nonnative fish into Grand Canyon, their movement patterns, and areas important for their spawning and recruitment. These areas could then be targets for removal efforts.	1. Improve monitoring 2. Initiate tributary monitoring 3. Research sources of nonnative fish 4. Continue testing remote PIT-tag reader 5. Implement sonic telemetry
Prevent new nonnative fish invasions into Grand Canyon from illegal stocking or sources such as tributaries and Lakes Mead or Powell.	See related ~~recommendation~~options above and: 1. Prevent nonnative fish invasions 2. Improve public education and outreach 3. Conduct annual workshop 4. Develop standard reporting procedures
Apply localized control strategies in areas important for native fish that would likely be most feasible and efficient for nonnative fish control. This would require the development of effective capture methods that would reduce target nonnative fish populations in localized applications. Other control could include systemwide manipulations through dam operations.	1. Continue mechanical removal 2. Initiate removal in tributaries 3. Initiate catfish and bullhead removal in Little Colorado River 4. Undertake chemical renovation and barrier construction 5. Investigate carp netting 6. Develop dam release strategy to disadvantage nonnative fish 7. Explore daughterless technology for future use 8. Investigate future use of infectious agents
Improve monitoring programs to identify changes in native and nonnative fish populations of concern and multiple life history stages within those populations. Monitoring data should allow scientists adequate detection of changes in abundance and distribution of a species. This change can then be related to the impacts of management activities or other factors that may contribute to population change.	1. Improve monitoring 2. Develop occupancy models 3. Continue testing of remote PIT-tag detectors 4. Investigate carp netting 5. Implement sonic telemetry 6. Conduct annual workshop 7. Develop contingency plans
Develop effective detection programs to identify new invading nonnative fish. Ideally, detection of new invaders would be timely to allow for an effective response from managers and cooperating agencies before the invading population reproduces in or invades the mainstem Colorado river where control efforts may be less effective.	1. Improve monitoring 2. Initiate tributary monitoring 3. Research sources of nonnative fish 4. Develop occupancy models 5. Develop contingency plans
Use best professional judgment and consensus in the absence of definitive answers to determine nonnative fish control implementation strategies.	1. Improve monitoring 2. Develop risk assessment 3. Conduct annual workshop
Develop Grand Canyon contingency and response plans for management agencies to implement cooperative efforts in addressing urgent nonnative fish expansions or invasions to protect native fish.	1. Develop contingency plans 2. Improve monitoring

Develop contingency fund for emergency control responses to nonnative fish issues while protecting funding for monitoring programs. Monitoring is important for evaluating the effects of emergency control responses.	1. Develop contingency plans 2. Improve monitoring

The range of strategies and actions presented above will take time to implement. An assessment of available data related to nonnative fish in Grand Canyon and subsequent identification of information gaps will assist in the development of planning and research strategies. Filling data gaps that are identified will also take time, which forces scientists and managers to make decisions in the absence of all possible information. The approach described above attempts to balance the recommendations made for research needs with the application of control options and the improvement of monitoring programs. However, research and monitoring improvement recommendations outnumber control ~~recommendation~~options, a balance that accurately reflects the current state of knowledge regarding nonnative fish in Grand Canyon. This situation may force managers to make decisions based on the best available information, which may not resolve critical nonnative fish management questions. ~~Recommendation~~Options for nonnative fish management approaches and ~~priorities~~ prioritization of options ~~may~~ will change over time as new information is evaluated from annual nonnative fish workshops, literature reviews, continued evaluation of monitoring needs and results, and development of new capture methods. This approach is consistent with the general philosophy of adaptive management of increasing knowledge while simultaneously attempting to minimize risk to native fish.

Nonnative fish management in Grand Canyon is complex and falls under the jurisdiction of many State, Tribal, and Federal agencies (See Regulatory Authority Section above). Land ownership within the Grand Canyon watershed is also varied, including lands managed by State, Tribal, and Federal entities as well as private landowners, demonstrating the complexity of managing sources of nonnative fish into Grand Canyon (fig. 7). Because of this complexity, management of nonnative fish and their sources in Grand Canyon and the watershed will require coordination and cooperation of resource and land management agencies, the Tribes and scientists.

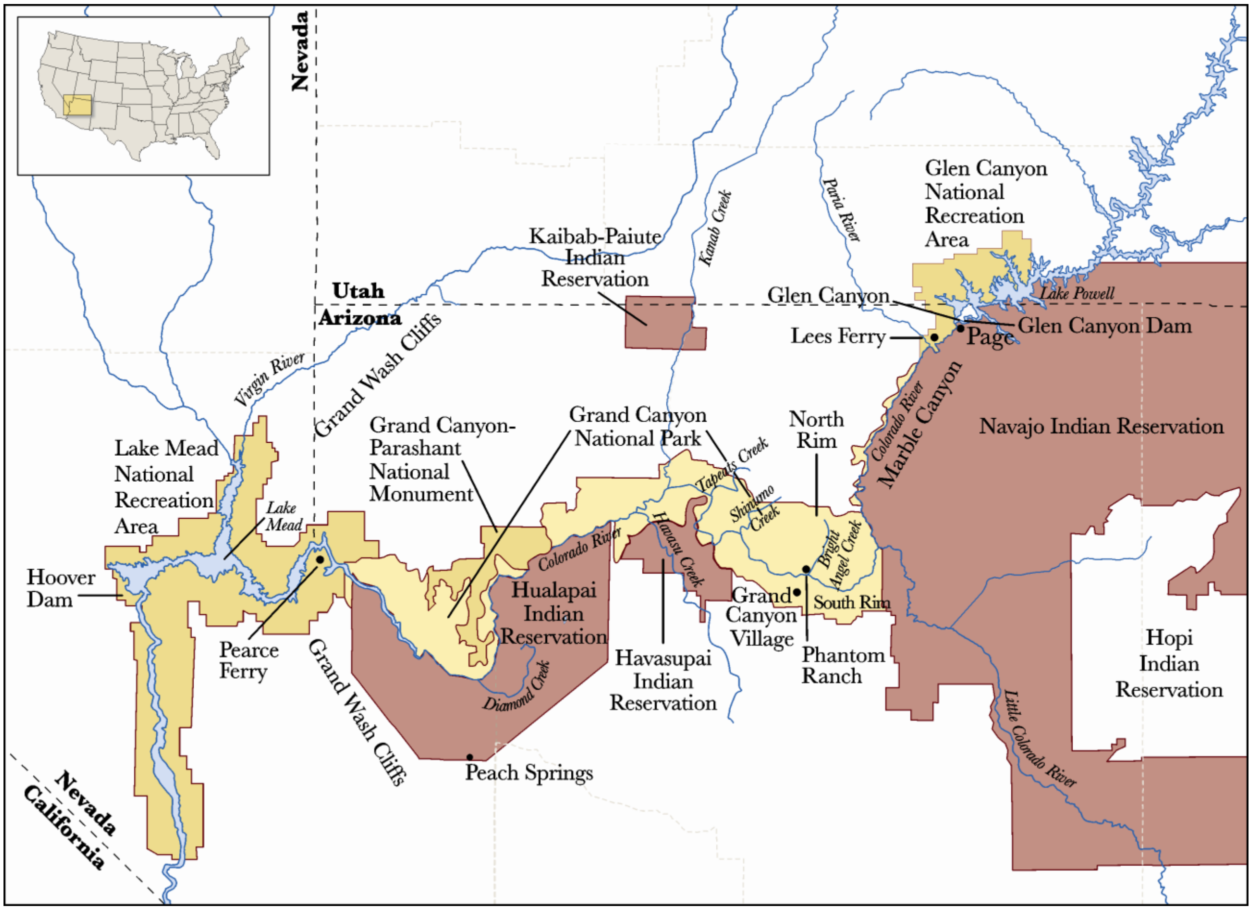


Figure 9. Map of the Colorado River ecosystem, showing the Colorado River corridor and surrounding land ownerships.

Tribal Concerns

There are long-standing concerns by Native American stakeholders about conducting nonnative fish control in culturally sensitive areas of the Grand Canyon. The Tribes advocate for collaboration with management agencies and scientists and request the involvement of tribal people early in the stages of nonnative fish control planning so they are actively involved in forming management questions and plans. The Tribes request that genuine consideration of cultural values and interests be incorporated into designing and carrying out research and management activities of the GCDAMP. The Tribes believe true collaboration should occur throughout project planning, execution, analysis, and dissemination of results and should actively involve tribal members such as students, elders, and others interested to consider culturally-sensitive perspectives of the Tribal members. This Tribes believe this communication would broaden the perspective of the Grand Canyon ecosystem beyond that of Western science (K. Dongoske, Pueblo of Zuni, pers. commun., 2010).

Communication with Tribal should occur in accordance with Secretarial Order 3206 (05 June 1997), entitled “American Indian Tribal Rights, Federal-Tribal Trust Responsibilities, the Endangered Species Act, and Section 106 of the National Historic Preservation Act. Specifically, Principles 1 and 4 of SO 3206 direct the Department of Interior to work directly with Indian Tribes on a government-to-government basis to promote healthy ecosystems and to be sensitive to Indian culture, religion, and spirituality. Additionally, Executive Order 13007 states that federal agencies shall accommodate access to and ceremonial use of Indian sacred sites by Indian religious practitioners and that the federal agency shall avoid adversely affecting the physical integrity of such sacred sites (Pueblo of Zuni, 2009).

Integration of Science and Management

The recommendations and options contained within this document bridge the roles of both science and management. Recommendations relating to science generally include the development of nonnative fish monitoring programs to track progress in achieving GCDAMP goals, researching information needs to develop nonnative fish control strategies and risk assessments, and testing nonnative fish capture techniques. Management related ~~recommendation~~options include tributary renovations and barrier construction, development of public outreach products, consensus regarding agency roles in the development of contingency and response plans, and long-term management and removal of nonnative fish using prescriptions developed and tested through the scientific process. Each component of this ~~plan~~document, both science and management related, are vital for the successful development and implementation of nonnative fish control strategies in Grand Canyon.

Better integration of the nonnative fish research and monitoring components with the implementation and prioritization of nonnative fish control projects by the management agencies is necessary. The GCMRC recommends that a nonnative fish workshop be conducted annually with scientists, managers, and other outside experts, including scientists from the upper Colorado River Basin to discuss implementation of nonnative fish management planning. An annual workshop would allow scientists to discuss their most recent monitoring and research results, continue to identify information gaps, and develop and prioritize recommendations and options for nonnative fish ~~control needs~~in Grand Canyon. With this information, managers could then prioritize control projects and develop implementation strategies to satisfy GCDAMP and management agency missions, goals, and objectives for nonnative fish management in Grand Canyon.

Prioritization of Projects

The ~~recommendation~~options presented by this ~~plan~~document exceed the budgetary limits of the GCDAMP. Therefore, scientists and managers must prioritize ~~recommendation~~options for nonnative fish control planning. Information gaps exist in the knowledge of nonnative fish parameters in Grand Canyon that make prioritizing ~~recommendation~~options difficult. The prioritization of ~~recommendation~~options presented here and during previous nonnative fish workshops has been criticized because of a lack of objective prioritization criteria. Prioritization methods described below, however, contain evaluation and prioritization criteria that are based on subjective opinions of experts. In the absence of definitive answers to basic questions regarding the impact of nonnative fish on native fish that would directly impact prioritization criteria, scientists and managers are forced to use their best professional judgment in deciding how best to prioritize nonnative fish control planning activities.

Prioritizing ~~options and recommendations~~potential solutions-formulated among a diverse group of stakeholders in a data-poor situation had been approached using various methods. One example of developing consensus is called the Delphi method (Dalkey and Helmer 1963). This method employs an iterative process where criteria are ranked or unknown biological parameters are estimated by polling experts who remain anonymous to each other. This method allows respondents to research their answers, consider the responses of other anonymous participants, and revise their opinions. This method assists in reducing the spontaneity of responses in face-to-face discussions and allows for controlled feedback, thereby generating more accurate responses (Dalkey 1969; Clark and others 2006). Hess and King (2002) used the Delphi method to identify focal species that were used to develop open space management plans to benefit wildlife. Barrett (2009) used the Delphi method to query experts on life-history ratios for the Devil's Hole pupfish (*Cyprinodon diabolis*) where such values were not available. Average parameter values developed by respondents were then incorporated into a population viability model. The author stresses the notion that the survey results assist in decisionmaking in the absence of empirical information, however, the pursuit of information must continue. The criteria used in each survey should be carefully selected to address the required decisions. Another example is the Upper Colorado River Endangered Fish Recovery Program Nonnative Fish Sub-Committee use of a ranking method for prioritizing nonnative fish related tasks (See appendix C, included with permission of T. Chart, U.S. Fish and Wildlife Service). This method closely patterns that of the Yampa River Strategy (Chart and others, 2008) by using numerical ranking (0 to 5) of criteria based on subjective opinion of scientists and managers involved in the program. The first step was to consolidate a list of all the recommendations program participants developed related to nonnative fish management. The recommendations were grouped into categories of (1) prevention, (2) research, (3) mechanical removal, and (4) policy. The list within each category was then ranked based on (1) technical feasibility, (2) time to implement, (3) cost, and (4) effectiveness. Project ranks were placed in a bivariate chart based on cost effectiveness and ease of implementation where projects fell into four categories: (1) difficult but big pay off = medium priority, (2) easy and cost effective = high priority, (3) easy but questionable outcome = medium priority, and (4) difficult and questionable outcome = low priority. Methods similar to these examples could be used by the GCDAMP to define priority tasks and assist in the development of nonnative fish management and research implementation strategies. Adoption of a particular prioritization process should be discussed among scientists and managers during the annual nonnative fish workshop.

Desired Future Conditions

The formulation of desired future outcomes by the GCDAMP could assist scientists and managers in developing and prioritizing nonnative fish control in Grand Canyon. Development of well-defined conditions that are agreed upon by the GCDAMP stakeholders, including management agencies, will then assist with developing goals for nonnative fish control. This clarification will assist in the identification of information needs and the development of specific management approaches for managers and scientists to work together toward achieving desired future conditions.

Monitoring and Research

Developing a risk assessment and improving nonnative fish monitoring information in Grand Canyon are two of the top priorities that emerged as the result of discussions among nonnative fish workshop participants and reviewers of this document. As the science provider to GCDAMP, the GCMRC and cooperators will implement several monitoring and research recommendations presented by this document to address these priorities as well as others in FY 2010 and 2011. Implementation of these projects is consistent with the FY2010–11 budget and work plan approved by AMWG in August 13, 2009 (table 5), and subsequently approved by Secretary of the Interior Salazar in November 2009. Monitoring projects to be conducted in FY 2010 and 2011 include (1) monitoring nonnative fish near humpback chub aggregations and tributary inflow areas and (2) developing early detection protocols for nonnative fish in the Lees

Ferry reach. Nonnative fish research projects to be conducted in 2010 and 2011 include (1) developing a nonnative fish risk assessment, (2) researching sources of nonnatives into the Grand Canyon and potential control options, (3) evaluating the utility of an occupancy model for monitoring rare nonnative fish species, (4) evaluating small-bodied fish monitoring techniques using slow shocking, (5) investigating the feasibility of using sonic tags to evaluate native and nonnative fish habitat overlap, and (6) continuing evaluation of remote PIT-tag detectors for use in determining native and nonnative fish movement patterns in the Little Colorado River.

Control

With finding form the GCDAMP, the GCMRC and Arizona Game and Fish Department are currently scheduled to continue the mechanical trout removal project near the Little Colorado River confluence area in FY 2010 and 2011 (table 5). The techniques used to remove trout have been researched and developed through the scientific process. As part of this project, abundance of native and nonnative fish is closely monitored to evaluate the impacts of removal or other factors on fish abundance. Evaluating the effect of removing trout on local trout abundance has been complicated by other factors such as warm water temperatures and food base effects. However, scientists believe an efficient method to capture trout has been developed for agencies to apply to trout management in Grand Canyon.

Implementation of other control ~~recommendation~~options will require agreement among management agencies regarding their roles and responsibilities in achieving the goals of the GCDAMP as well as the resource management goals of each agency. Goals for nonnative fish management will require coordination of management agencies and integration of their respective management objectives. Also, agreement among stakeholders regarding the terms “management action” and “experiment” will be required for effective planning for nonnative fish control actions. For example, the mechanical trout removal project is still considered to be experimental under the auspices of the GCDAMP, however, there is disagreement among stakeholders as to a programmatic definition of an experimental project versus a management action. Defining experimental projects and management actions will further assist management agencies in clarifying their roles and responsibilities for nonnative species management in Grand Canyon. This will assist GCDAMP stakeholders in implementing present and future nonnative fish control needs. (See Aug 13, 2009 AMWG motion for Science Advisors to survey other adaptive management programs to define research versus management actions.)

Rapid Response Plans

In order to respond rapidly and effectively to an invasion of nonnative species, actions should be anticipated and consensus reached on as many response details as possible before the discovery of the invasion or population expansion. When a response is needed, consensus regarding actions, funding sources, and agency responsibilities will result in a rapid and more effective response. Currently, the GCDAMP does not have a rapid response plan in place for invasions or expansion of nonnative aquatic species. Development of a rapid response plan by the GCDAMP (See appendix D) may assist in managing the complexity of nonnative fish control and planning in Grand Canyon.

The Washington State Aquatic Nuisance Species Committee (2005, See appendix D) drafted an early detection and rapid response plan for aquatic invaders in the Columbia River Basin involving fourteen Federal, State, Tribal, and private entities. The plan for the Columbia River basin provides many pre-determined management agency responses and establishes a decision making infrastructure designed to facilitate rapid resolution of issues. The response plan contains a number of objectives and related tasks and identifies remaining institutional and legislative gaps that need to be addressed. Objectives in this plan include (1) ensure early reporting of new invasions, (2) ensure new species identification and risk assessments, (3) define decisionmaking responsibility and response protocols, (4) establish and maintain capacity to act, and (5) incorporate adaptive management in plan implementation. The goal of maintaining the capacity to act includes (1) development of a response fund; (2) identification and elimination of barriers to response such as indecision, funding, and logistical issues; and (3) develop and conduct training for rapid responders. Also included in this document is an appendix summarizing Federal, State, and Tribal policy and laws pertaining to invasive species. The approach taken by the Washington committee has been used as a template for the development of many other rapid response plans in other programs and also provided guidance for this document.

Development of a rapid response plan for nonnative aquatic species by members of the GCDAMP would assist in defining agency roles and responsibilities and increase the likelihood of successful control of the expansion or invasion of nonnative species in Grand Canyon.

Cost Estimates

Estimating project costs is difficult because it is not possible to determine which nonnative species may impose the greatest risk to natives, when and where these effects will occur, and how to reduce them. Prioritization of projects given limited funding is also difficult because of the unknown conditions indicated above. The GCMRC will implement the monitoring and research components of this ~~plan~~document in FY 2010 and 2011. Cost estimates for these components have been included in the table 5. Costs for control projects will be more accurately developed as agency roles and responsibilities are defined and control projects are prioritized in the near future. The features of a contingency plan and the associated costs will be determined by the effectiveness of available reduction methods and the extent of the area to be treated. Cost estimates for higher priority projects are more certain than lower priority.

In 2009, the cost of one trip to mechanically remove rainbow trout and other nonnative fish from the mainstem Colorado River in the vicinity of the mouth of the Little Colorado River is approximately $150,000. This amount includes two nights of sampling in a control reach upstream of the removal reach to estimate the nonnative fish population. Following the control reach sampling, six passes of the removal reach are conducted using boat-mounted electrofishing. Other control efforts may differ as the result of many factors, including target species, gear types, location, time required, other equipment required, and other factors. Therefore, the 2009 mechanical removal project cost may not accurately represent the costs of all possible control efforts, but it does provide a known starting point for estimating possible future efforts.

Table 5. Summary of nonnative fish monitoring and research recommendations and control options included in the Grand Canyon Monitoring and Research Center work plan for fiscal years 2010–11, including project numbers and gross project costs. NA = not applicable.

Nonnative Fish Project	GCMRC FY 10-11 work plan reference	Gross Project Cost	
		FY10	FY11
Monitoring			
Expanding current mainstem nonnative fish monitoring protocols	BIO 2.M4.10-11. Monitoring Mainstem Fishes	$632,461	$798,930
Implementing early detection protocol and nonnative fish monitoring in Lees Ferry	BIO 4.M2.10-11. Monitoring Lees Ferry Fishes	$175,737	$182,819
Research			
Developing a model to identify the nonnative species posing the greatest risk to humpback chub			
Identifying sources of juvenile and adult nonnative fish into the mainstem such as recruitment locations, tributary inflows, dam passage, and illegal stocking	BIO 2.R17.10-11. Nonnative Control Plan Science Support	$78,057	$138,599
Developing occupancy modeling for improvement of long-term nonnative fish monitoring, evaluation of nonnative fish population expansion or contraction, and development of early detection protocols			
Testing carp capture methods using large mesh nets			
Developing risk assessment and evaluation of occupancy model	Some modeling also conducted in: Plan 12.P1.10-11. Identify Critical Ecosystem Interactions and Data Gaps	$239,986	$148,945
Conducting a small-bodied nonnative fish and YOY capture and monitoring study using slow-shocking techniques (nearshore ecology) throughout the mainstem	BIO 2.R15.10-11. Nearshore Ecology/Fall Steady Flows	$552,825	$556,911

Conducting sonic telemetry studies for native and nonnative fish to compare and identify spatial and temporal movement patterns, tributary use, and spawning areas			
Removal			
Maintaining trout abundance in the Little Colorado River confluence area at approximately 20 percent of January 2003 rainbow trout abundance	BIO 2.R16.10-11. Mainstem Nonnative Fish Control	$246,966 $ 68,842	$309,251
Continuing removal of trout in Shinumo Creek using backpack electrofishing in combination with other methods such as weirs and angling to support translocation efforts	Not in GCMRC work plan, but has been conducted by NPS, AZGFD, GCWC in conjunction with HBC translocation to Shinumo	NA	NA
Other recommendations and options			
Conducting an annual nonnative fish workshop with cooperators and other nonnative fish experts to review current information and to help prioritize efforts	BIO 2.R17.10-11. Nonnative Control Plan Science Support	$78,057	$138,599
Developing a formalized reporting procedure for nonnative fish captured and observed by professional entities performing sampling within Grand Canyon			
Contingency planning			
Defining agency roles and developing rapid response plans to nonnative fish expansions or new invasions	BIO 2.R17.10-11. Nonnative Control Plan Science Support (discussed at annual nonnative meeting)	$78,057	$138,599
Evaluating response triggers to initiate control measures of nonnative fish abundance from changes in catch rate, distribution, species composition, and length frequencies (reviewed at annual nonnative meeting)			
Applying current capture methods used in Grand Canyon while more effective methods are being developed	BIO 2.R16.10-11. Mainstem Nonnative Fish Control	$246,966 $ 68,842	$309,251
Implanting sonic tags in nonnative fish to help evaluate dispersal, potential spawning activities, and other factors	BIO 2.R15.10-11. Nearshore Ecology/Fall Steady Flows (further investigating sonic tags)	$552,825	$556,911

Establishing a nonnative fish contingency fund for ongoing monitoring and research activities	Described in Plan and being discussed with AMP committees	NA	NA

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Appendix A. Abridged Species Description for Nonnative Fish of Concern

The following descriptions of known Grand Canyon nonnative fish species of concern are adapted from Scott and Crossman (1973), Lee and others (1980), Ross and Brennenman (2002), Fuller (2008a, b, c, d, and e), Nico and Fuller (2008), and Nico and others (2008).

Common Carp (*Cyprinus carpio*)

Description

The common carp is one of the most popular sport fish in Europe and its popularity is growing in the United States.

Habitat

The native range of this species is in Europe and Asia. It has been widely introduced throughout the North America and other continents. Common carp generally inhabit lakes, ponds, and the lower sections of rivers and can be found in brackish-water estuaries, backwaters, and bays; they are less abundant in clear waters or streams with a high gradient (Pflieger, 1975; Trautman, 1981; Ross, 2001; Boschung and Mayden, 2004).

Distribution in Grand Canyon

Carp are found throughout the mainstem of the Colorado River but are more commonly captured downstream of the Little Colorado River confluence area. Carp captures generally increase with downstream distance.

Life History

Larval carp feed primarily on zooplankton. Juveniles and adults feed on benthic organisms (for example, chironomids, gastropods and other larval insects), vegetation, detritus, and plankton (for example, cladocerans, copepods, amphipods, mysids; Summerfelt and others, 1971; Eder and Carlson, 1977; Panek, 1987).

Carp spawn in aggregations from early spring into late fall, often migrating to suitable areas. Adult females can spawn up to three times in a season (Smith and Walker, 2004). Carp have a fecundity of 163,000 eggs per kilogram whole female weight (Sivakumaran and others, 2003). Spawning may occur in rivers, lakes, and shallow streams.

Potential Impacts in Grand Canyon

Common carp may prey upon the eggs of other fish species (Moyle, 1976; Taylor and others, 1984; Miller and Beckman, 1996). Silt resuspension and uprooting of aquatic plants caused by feeding activities can disturb spawning and nursery areas of native fishes (Ross, 2001). Common carp are currently found in Grand Canyon, have expansion potential in warming water, and also co-occur with humpback chub in the Little Colorado River.

Methods for Management

Piscicides such as antimycin and rotenone are effective toxicants for common carp. Carp selective traps have been developed based on behavioral characteristics of carp during spawning migrations. Baiting stations have been developed to deliver poison bait and other piscicides specifically to carp. Attractants, genetic manipulation, and disease vectors are currently being investigated. Identification of carp "hot spots," areas of high carp densities where spawning or migration concentrate carp, is a technique currently used in many carp control programs. Identification of these hot spots is done through telemetry, isotope analysis, and larval drift samples. These areas are then targeted with mechanical and chemical removal programs.

Fathead minnow (*Pimephales promelas*)

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Description

The fathead minnow is a popular bait and forage fish in many areas of the Colorado River Basin.

Habitat

This species is native to much of North America from Quebec to the Northern Territories, south to Alabama, Texas, and New Mexico, and the Mississippi and Rio Grande River Basins (Page and Burr, 1991). It inhabits streams, rivers, ponds and lakes.

Distribution in Grand Canyon

Fathead minnows are captured most frequently in backwaters throughout the Colorado River below the Little Colorado River Confluence (Ackerman, 2007).

Life History

Fathead minnows are schooling fish, feeding primarily on plant material and small invertebrates. This species is able to tolerate a wide range of environmental conditions, including high temperatures, low oxygen levels, and high turbidities. Fathead minnows tend to disperse downstream (Schlosser, 1995).

Spawning is prolonged from late spring through midsummer. Eggs are deposited over submerged objects. Fathead minnows are one of the only cyprinids in which the males nest guard. Nests may contain as many as 12,000 eggs, and females may spawn as many as 12 times in a single summer. Annual fecundity ranges from 7,000 to 11,000 eggs per female. Some individuals may mature and spawn during their first summer of life, but spawning is usually delayed until the second summer (Gale and Buynak, 1982).

Potential Impacts in Grand Canyon

Fathead minnows have been implicated as a threat to young of the Colorado pikeminnow (*Ptychocheilus lucius*) in the upper Colorado River Basin (Karp and Tyus, 1990). Fathead minnow colonization was determined to cause food web changes (Zimmer and others, 2001) and increases in turbidity (Ross, 2002).

Methods for Management

Piscicides such as antimycin and rotenone are effective toxicants for the fathead minnow. Fish can be captured using seines; however, the effect of capture on the total population numbers is not known.

Increasing flows and reducing water temperature may temporarily reduce fathead minnow abundance (Lentsch and others 1996; Valdez and Ryel 1995).

Brown trout (*Salmo trutta*)

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Description

The brown trout is a popular sport fish in many areas of the Colorado River Basin.

Habitat

This species is native to lakes and streams in Europe, northern Africa, and western Asia (Page and Burr, 1991). It generally inhabits cool water streams, rivers, and lakes with gravel and cobble substrates (Scott and Crossman, 1973).

Distribution in Grand Canyon

Brown trout were introduced in Grand Canyon and its tributaries in the early 1900s. They are captured in greatest abundance in proximity to the confluence of Bright Angel Creek (Rogers and Makinster, 2006). Brown trout are also captured in several Grand Canyon tributary streams including Bright Angel, Tapeats, and Kanab Creeks (Leibfried and others, 2003).

Life History

Brown trout prefer water temperatures less than 16°C. They feed on benthic invertebrates, insect larvae, terrestrial insects, and mollusks. In addition, adults consume fish, small mammals, young water fowl, and frogs (Kelly-Quin and Bracken, 2008).

Spawning generally occurs in the fall in clean gravel and small cobble substrates (Behnke, 2002). Fertilization is external, with the female trout excavating a redd in streambed gravels. Fecundity ranges from 200 to 2,400 eggs per female, and once eggs are fertilized, the female covers the redd with gravel (Taube, 1976). Larval brown trout become free-swimming fry 3–7 d after hatching (Behnke, 2002). Small juveniles are benthopelagic, remaining in the substrates, while larger juveniles are pelagic, venturing into the water column (Morrow, 1980).

Potential Impacts in Grand Canyon

Native fish are preyed upon by brown trout in Grand Canyon (Valdez and Ryel 1995; Marsh and Douglas 1997). Brown trout were introduced into Flaming Gorge Reservoir to reduce populations of the Utah chub (*Gila atraria*; Teuscher and Luecke, 1996).

Methods for Management

Piscicides such as antimycin and rotenone are effective toxicants for brown trout. Extended desiccation of redds can cause mortality of trout eggs and sac fry (Korman and others, 2005). Electrofishing could also reduce brown trout abundance (Coggins, 2008). Mechanical removal using a weir or electrofishing during spawning migrations of brown trout into Bright Angel Creek may reduce abundance and reproductive success (Sponholtz and VanHaverbeke, 2007).

Rainbow trout (*Oncorhynchus mykiss*)

Description

The rainbow trout is a popular sport fish in many areas of the Colorado River Basin.

Habitat

This species is native to the Pacific Slope from Alberta, British Columbia, and Alaska, and south to Baja, California (Page and Burr, 1991). It generally inhabits cold water streams, rivers, and lakes with gravel and cobble substrates (Scott and Crossman, 1973).

Distribution in Grand Canyon

Rainbow trout were introduced in Grand Canyon and its tributaries in the early 1900s. They are captured in greatest abundance from Glen Canyon Dam to Bright Angel Creek (Rogers and others, 2008). Rainbow trout are also captured in several Grand Canyon tributary streams, including the Little Colorado River, Bright Angel, Shinumo, Kanab, and Tapeats Creeks (Leibfried and others, 2003).

Life History

Most rainbow trout are capable of migrating, or at least adapting to sea water. Rainbow trout prefer water temperatures of less than 12°C. Adults feed on aquatic and terrestrial insects, mollusks, crustaceans, fish eggs, minnows, and other small fish, including small trout; young feed predominantly on zooplankton (Behnke, 2002)

Spawning generally occurs in the spring in clean gravel and small cobble substrates (Behnke, 2002). Fertilization is external, with the female trout excavating a redd in streambed gravels. Fecundity ranges from 700 and 4,000 eggs per female, and once eggs are fertilized, the female covers the redd with gravel (McDowall, 1990). Larval rainbow trout become free swimming fry 3–7 d after hatching (Behnke, 2002). Small juveniles are benthopelagic, remaining in the substrates. while larger juveniles are pelagic, venturing into the water column (Morrow, 1980).

Potential Impacts in Grand Canyon

Rainbow trout have been shown to consume humpback chub in the Little Colorado River (Marsh and Douglas, 1997). Rainbow trout may exert other negative impacts on native fish through competition.

Methods for Management

Piscicides such as antimycin and rotenone are effective toxicants for rainbow trout. Extended desiccation of redds can cause mortality of eggs and sac fry (newly hatched trout with attached egg yolks; Korman and others, 2005). Gill netting was effective in reducing rainbow trout abundance in alpine lakes (Knapp and Matthews, 1998). Electrofishing can also be used to reduce rainbow trout abundance (Coggins, 2008).

Bullhead (*Ameiurus spp.*)


© Duane Raver/USFWS

Description

The bullhead is considered a rough fish and is not commonly eaten, although it is edible.

Habitat

The native range of the black bullhead (*Ameiurus melas*) included the central plains west of the Appalachians and east of the Rockies, extending north into Saskatchewan and Manitoba, and south into south Texas and New Mexico. The native range of the brown bullhead (*Ameiurus nebulosus*) is from the Atlantic and Gulf Slope drainages from Nova Scotia and the St. Lawrence River, Great Lakes, Hudson Bay, and Mississippi River Basins in southeastern Saskatchewan, and south to Louisiana (Page and Burr, 1991). Both species inhabit ponds, lakes, and slow-flowing streams and rivers, preferring soft bottom substrates (Mayhew, 1987).

Distribution in Grand Canyon

Bullheads are almost exclusively captured in the Little Colorado River and in the immediate proximity of the Colorado River confluence (Ackerman, 2007; U.S. Geological Survey, unpub. data, 2008).

Life History

More tolerant than other catfish of muddy, brackish water, low oxygen, and pollution, bullheads are omnivorous, feeding primarily from the bottom on a wide range of plant and animal material, both live and dead. Bullheads feed extensively on aquatic insects, small crayfish, worms, small mollusks, crustaceans; they have been known to eat the eggs of other fish, as well as feeding extensively on minnows. Fathead minnows are of particular importance in their diet in the Iowa Lakes (Mayhew, 1987). Bullheads are more active at night, especially at dusk, when they move from deep to shallow water (Dedual, 2004).

During late spring or early summer when water temperatures reach 70°F, bullheads excavate nests in mud bottoms under cover in about 0.6 to 1.2 m of water. The female lays 2,000 to 6,000 eggs. Nests are guarded by both parents and eggs hatch in 4 to 6 d. Fry begin to school in compact balls, which are guarded by adults until fry reach about 25 mm in length (Mayhew, 1987).

Potential Impacts in Grand Canyon

Black bullheads have been shown to consume humpback chub in the Little Colorado River and may exert a major negative effect on the population there (Marsh and Douglas, 1997). Minckley (1973) reported that this species is generally considered a pest in Arizona because it forms large stunted populations that compete with more desirable fish for space and food.

Methods for Management

Piscicides such as antimycin and rotenone are effective toxicants for the bullhead. Fish can be captured using angling and baited hoop nets; however, the effect of capture on the total population numbers is not known.

Channel catfish (*Ictalurus punctatus*)

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Description

The channel catfish is North America's most numerous catfish species and is an important sport fish to the angling community across the United States.

Habitat

The channel catfish’s native range is the central drainages of the United States. It is now found throughout big rivers and streams across the United States preferring deep lotic environments with sand, gravel, or rubble bottoms. Channel catfish also inhabit lakes, reservoirs and ponds.

Distribution in Grand Canyon

Channel catfish were stocked into the Colorado River in the early 1900s and were commonly captured in Grand Canyon before the construction of Glen Canyon Dam (Woodbury, 1959). Channel catfish are currently found throughout the mainstem Colorado River and its tributaries in Grand Canyon. Captures of channel catfish are most common in the Little Colorado River and below Lava Falls Rapid to Lake Mead.

Life History

Channel catfish feed primarily at night and on the bottom of streams or pond. Major foods are aquatic insects, crayfish, mollusks, crustaceans, and fish. Young channel catfish consume invertebrates, but larger ones may eat fish.

Channel catfish usually become sexually mature at 3 yr of age with spawning occurring mostly in rivers and streams in the spring and early summer when waters warm to 21°C to 29°C. Wild populations of channel catfish may spawn as early as late February or as late as August, depending on the location. Water temperatures below 18°C and above 30°C will reduce hatching success. Male channel catfish select secluded nest sites under banks or logs. Females spawn only once a year and produce about 6,600 to 8,800 eggs per kilogram of body weight. Eggs hatch in 6 to 10 d, depending on water temperature. The male guards the eggs and young until approximately 7 d after hatching.

Potential Impacts in Grand Canyon

Channel catfish may exert negative impacts on native fish through predation and competition during all life-history stages. Channel catfish are currently found in Grand Canyon and have expansion potential in warming water. Channel catfish also co-occur with humpback chub in the Little Colorado River. They were believed to be the greatest threat to endangered fish in the Upper Basin in 1991 (Hawkins and Nesler, 1991).

Methods for Management

Piscicides such as antimycin and rotenone are effective toxicants for channel catfish. Hoop nets and slat traps baited with cheese bait or dog food and angling are effective methods to capture channel catfish. The efficacy of mechanical techniques in reducing channel catfish abundance is not certain.

Smallmouth Bass (*Micropterus dolomieu*)

© Duane Raver/USFWS

Description

The smallmouth bass is a popular sport fish in many areas of the Colorado River Basin.

Habitat

This species is native to the St. Lawrence-Great Lakes system, Hudson Bay, and Mississippi River Basins. This species generally inhabits shallow rocky areas of lakes, clear and gravel-bottom runs, and flowing pools of rivers and shallow streams (Scott and Crossman, 1973)

Distribution in Grand Canyon

Smallmouth bass were first discovered in Grand Canyon with the capture of a 348-mm adult fish in April 2003 2 mi downstream of Glen Canyon Dam. Subsequently, in April 2004, a 70-mm juvenile fish was captured 5 mi downstream of the dam.

Life History

Young smallmouth bass feed on plankton and immature aquatic insects, and adults prey upon crayfish, fish, and aquatic and terrestrial insects, and can be cannibalistic (Scott and Crossman, 1973; Etiner and Starnes, 1993).

Smallmouth bass generally spawn in the late spring when the water temperature is from 15°C to 18°C. The male builds a shallow plate-like depression in 0.7–3.0 m of water. Nests are constructed in shallow waters of lakes and rivers, on sand, gravel, or rocky bottoms. Eggs are deposited in the nest and fertilized by the male and typically hatch in 10 d. Males guard the nests and young.

Potential Impacts in Grand Canyon

Smallmouth bass have been implicated in the decline of bonytail chub(*Gila elegans*), humpback chub, and roundtail chub (*Gila robusta*), as well as other native species in the Colorado River Basin. Smallmouth bass have demonstrated invasion and rapid expansion potential in the upper Colorado River Basin (Fuller, 2007).

Methods for Management

Piscicides such as antimycin and rotenone are effective toxicants for smallmouth bass. Desiccation of smallmouth bass nests can cause 100-percent egg mortality with only 24 h of exposure to air (Benson, 1976). Disturbance of nests with high dam releases of cool water negatively impacted hatching success (Montgomery and others, 1980); however, Benson (1976) reported that high steady flows positively impacted hatching success. Electrofishing may reduce smallmouth bass abundance (Fuller, 2007).

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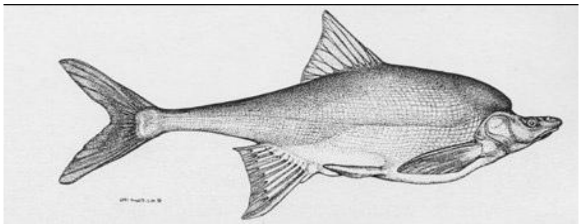
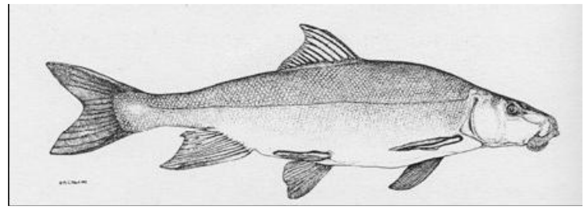
Appendix B. Public Information on Operation of Bright Angel Creek Temporary Weir

Public information fact sheet produced by Grand Canyon National Park and SWCA Environmental Consulting about operation of the Bright Angel Creek weir.



HUMPBACK CHUB



FLANNELMOUTH SUCKER

Bright Angel Creek Temporary Fish Weir

Purpose and Need: The National Park Service is charged with preserving and protecting the natural resources within Grand Canyon. Active hands-on management of resources is at times required to achieve this goal. In Bright Angel Creek, the fish community has been altered in favor of nonnative salmonids, to the detriment of its native fishes. Construction and operation of a temporary weir in Bright Angel Creek will help to determine whether removal of brown trout will promote native fish survival.

FAQs

What is a weir? Answer: A weir is a barrier to fish movement with an attached cage to capture and hold live fish.

Why are the trout being removed? Answer: Fish surveys have shown declines in native fishes concurrent with increases in brown trout. Brown trout are predators on the young and small native fish. Removal may increase the survival and numbers of native fish in Bright Angel Creek and help to restore the fish community.

What happens to the fish? Answer: The trout are taken from the cage and euthanized. They are measured and weighed, and examined for tags or marks. They are disposed of outside the park.

What about the rainbow trout? Answer: Rainbow trout will not be removed for this study.

Which are native fishes? Answer: The native fishes include the flannelmouth sucker, bluehead sucker, and speckled dace. The endangered humpback chub may once have lived in Bright Angel Creek; they still are occasionally found in the Colorado River nearby.

Who is responsible for this project? Answer: The National Park Service is funding this project. The contract to conduct the work and analyze the results was awarded to SWCA, an environmental consulting firm based in Flagstaff, Ariz.

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Appendix C. Nonnative Fish Sub-Committee Memo on Prioritized Recommendations from Past Nonnative Fish Workshops

Appendix D. Aquatic Nuisance Species Committee Rapid Response Plan