Southwest Biological Science Center, Grand Canyon Monitoring and Research Center

Study Plan—Biological Resource Responses to Fall Steady Experimental Flows Released from Glen Canyon Dam, 2009–12

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Executive Summary

Experimental steady releases from Glen Canyon Dam in September and October 2008 through 2012 (fall steady experimental flows, FSEF) were prescribed by a 2008 environmental assessment and an associated biological opinion. The Grand Canyon Monitoring and Research Center (GCMRC) prepared this science plan at the request of the Glen Canyon Dam Adaptive Management Work Group to examine the effects of FSEF on downstream resources. Four ongoing projects are collecting data that will be used to assess possible impacts of these flows on biological resources: (1) the nearshore ecology project, (2) stock assessment of native fish populations, (3) aquatic food base monitoring, and (4) monitoring of early life stages of rainbow trout. Given uncertainties regarding the extent and degree of nearshore warming that will occur as the result of fall steady flow operations, we propose the collection of new water temperature data in association with these flows. Physical and biological data will be integrated and synthesized using an ecosystem model to evaluate whether this management action had impacts on the ecosystem as a whole. A description of the sediment-monitoring program is not included in this document. However, the effects of the discharge regime on sediment resources are well understood, and the GCMRC Physical Sciences and Modeling Program could evaluate and report on the response of sediment resources to fall steady flows, should it be of interest to managers.

The GCMRC also has been asked to recommend flow parameters because the environmental assessment and biological opinion did not establish specific release rates for FSEF. Findings from recent studies indicate that lower flows result in greater abundance of backwater habitats, which are thought to be used by juvenile native fish, including the endangered humpback chub (*Gila cypha*). Thus, steady flows of about 8,000 cubic feet per second (cfs) for the remainder of the experiment (2010 through 2012) would likely maximize backwater habitat in addition to maximizing the potential for nearshore warming, also thought to benefit native fish. If water releases must be moved into other months of the year to accommodate these steady flows, it is recommended that releases in July and August not be increased. Daily peak discharges during July and August are already relatively high and further increases will increase sediment transport and sandbar erosion, which are undesirable side effects.

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Background

Need for Study

Regulation of the Colorado River by Glen Canyon Dam has eliminated spring snowmelt flood peaks, which historically occurred from April through early July, and increased discharge in summer, fall, and winter (Topping and others, 2003). The Bureau of Reclamation (Reclamation) has released or will release experimental steady flows from Glen Canyon Dam in September and October of 2008 through 2012 (fall steady experimental flows, FSEF) to partially mimic the steady and low flows that historically occurred annually from July to March. It is hypothesized that steady flows during the fall will benefit native fishes by stabilizing and warming the nearshore habitats that are occupied by juvenile (less than 150 mm total length) life stages of endangered humpback chub (*Gila cypha*) (Stone and Gorman, 2006). Fall steady flows may also affect other downstream biological resources, including the food base for native and nonnative fish.

The Glen Canyon Dam Adaptive Management Work Group (AMWG) requested that the Grand Canyon Monitoring and Research Center (GCMRC) develop a science plan for investigating the effects of FSEF. Glen Canyon Dam Adaptive Management Program participants, including natural resource managers and other stakeholders, want to know if the 2008–12 fall steady flows will affect humpback chub and other biological resources. One of the tenets of adaptive management is that learning about managed ecosystems can and should be gained by monitoring ecosystem responses to management actions (Williams and others, 2007; Souchon and others, 2008). Additionally, evaluation of natural resource responses to the 2008–12 FSEF is required by a 2008 environmental assessment (EA) (U.S. Department of the Interior, 2008). The studies outlined here will examine the effects of FSEF on downstream biological resources to advance adaptive management and ensure compliance with Federal environmental regulations.

Provisions of the Environmental Assessment and Biological Opinion

In February 2008, Reclamation released an EA (U.S. Department of the Interior, 2008) that built upon an earlier environmental impact statement for Glen Canyon Dam operations (U.S. Department of the Interior, 1995). The 2008 EA describes two flow experiments: (1) a 60-hour experimental high-flow release from Glen Canyon Dam in March 2008 and (2) steady releases in September and October of 2008 through 2012. The exact release volumes of the second experiment (FSEF) were not specified in the 2008 EA. As a result, in addition to examining the effects of the FSEF on biological resources, the GCMRC was asked by the AMWG to make recommendations for the volume of the fall steady flows, which are presented here. Recommendations for flows needed to evaluate whether a change in the lower limit of discharge, which, since 1996, has occurred between August and September, are also provided.

Evaluating the impacts of changing the lower limit of discharge on biological resources also was raised in the EA.

A 2008 biological opinion (BO) released by the U.S. Fish and Wildlife Service (U.S. Fish and Wildlife Service, 2008) called for two conservation measures that are addressed in this plan in response to the experimental flows. The conservation measures under the 2008 BO include the nearshore ecology project and a study of the impacts of flow transition, that is, the impacts of the flows fluctuating in August followed by reduced, steady flows in September during the experimental period. The BO suggested that the long-term impacts of the experimental flows would benefit humpback chub by creating and improving rearing habitats and increasing growth and survival. The BO also calls for monitoring the impacts of the March 2008 HFE and the fall steady flows on humpback chub.

There was not sufficient time to prepare this plan and implement the activities described herein during the 2008 FSEF; the GCMRC and its cooperators were preparing to undertake a substantial body of research associated with the March 2008 high-flow experiment (HFE) in February when the EA was released. However, there were ongoing studies during the 2008 FSEF, including a pilot project to start collecting data for the nearshore ecology project. Additionally, select biological resources were studied in association with the March 2008 HFE, and final reporting for all projects is nearly complete (Melis and others, 2010). Some baseline data from these studies are available and will be incorporated into the longer term studies.

Previous Experiments and Studies

Stable and low discharge is expected to benefit native fish in the Colorado River below Glen Canyon Dam by improving the quality of nearshore habitats that are occupied by juvenile life stages of native fish. Warming of nearshore water temperatures, stability of nearshore environments, and increases in food resources are the main habitat parameters that are hypothesized to improve with stable and low discharge. A number of these hypotheses have been investigated and the findings are summarized below.

Nearshore Water Temperature

The water temperature of nearshore habitats in the Colorado River is influenced by a variety of factors, especially the temperature of releases, air temperatures, the residence time of water in the mainstem, and the residence time of water in the nearshore environment (Korman and others, 2006; Wright and others, 2008). The elevation of Lake Powell and the thickness of the epilimnion have a major influence on release temperatures. In particular, the temperature of water discharged from Glen Canyon Dam during the summer of 2005 was 4°C warmer relative to the summertime average from 1989 to 2000 because of low Lake Powell elevations. The mainstem water temperatures observed between Glen Canyon Dam and the Little Colorado River in 2005 were warmer than temperatures observed in 2000, despite fluctuating flows in 2005 and steady flows in 2000, because of the lower elevation of Lake Powell in 2005 (B. Ralston, U.S. Geological Survey, written commun., 2009).

If air temperatures are warmer than water temperatures, heat energy is transferred from air to water and the water warms. Since 1994, water temperatures at Diamond Creek (river mile[1] (RM) 226, or 386 km below the dam) averaged 7.5°C warmer relative to releases in July but only 4°C warmer in October (Voichick and Wright, 2007; Wright and others, 2008). If air temperatures are cooler than water temperatures, then heat energy is transferred from water to air and the water cools; in December, water temperatures at Diamond Creek are on average slightly cooler (<1°C) than dam release temperatures. The amount of mainstem warming or cooling that occurs is positively related to water residence time, and the primary determinant of residence time is discharge volume (residence time decreases as discharge volume and average velocity increase). For example, water temperatures at Diamond Creek were 10°C warmer relative to releases in June 2000, when discharge was a constant 8,000 cubic feet per second (cfs), but only 5°C warmer during June of 1997, when discharge was a relatively constant 25,000 cfs (Vernieu and others, 2005).

If the residence time of water is sufficiently long, water temperatures of nearshore habitats can be different from the mainstem. For example, Korman and others (2006) found that water temperatures along high-angle shorelines—where water velocity is fast and residence time is short—were no different than the mainstem river across all months studied (mid-August through mid-November of 2004; three reaches were sampled: RM -3.5, RM 44.6, and RM 64.5). In contrast, daytime water temperatures in backwaters (longest water residence time) and low-angle shorelines (intermediate residence time) were about 2 and 1°C warmer, respectively, relative to mainstem temperatures in August. In September, when air temperatures were cooler but water residence time presumably was longer because of lower discharge volume and fluctuation range (10,000 to 18,000 cfs in August versus 5,000 to 10,000 cfs in September and October), water temperatures in backwaters and low-angle shorelines were about 3 and 2°C warmer than mainstem temperatures, respectively. However, in October, average daily air temperatures were cooler than water temperatures, and, as a result, water temperatures in these habitats were the same or slightly cooler than the mainstem. Thus, September and October represent a period of transition during which nearshore warming declines and eventually ceases, at least when discharge is fluctuating.

Mainstem and nearshore water temperatures for 42 miles of the Colorado River (RM 30 to 72) were measured using an aerially deployed thermal infrared sensor on July 21, 2000, around 1 p.m. local time as part of the low summer steady flow (LSSF) experiment (B. Ralston, U.S. Geological Survey, written commun., 2009). Resolution of these data were 1 m^2 and the total area of habitat within 2 and 4 m of shore were 446 ha and 804 ha, respectively. Water temperatures were warmer closer to the shore and ranged from 9 to 30°C (mainstem temperatures in this reach were about 13°C at the time), indicating significant nearshore warming can occur during the summer months when discharge is constant. However, 67 percent and 75 percent of the nearshore habitat within 2 and 4 meters of the shoreline, respectively, had water temperatures that were actually the same or slightly cooler than the mainstem. Unfortunately, thermal infrared images providing a comprehensive picture of nearshore water temperatures have not been collected during fluctuating operations at the same time of year as the low summer steady flow experiment, so it is difficult to put these data into context. That is, it is unclear whether nearshore habitats will gain increased water temperatures during steady flows relative to fluctuating flows.

[1] By convention, river mile (RM) is used to describe distance along the Colorado River in Grand Canyon: Lees Ferry (located 15.7 miles downstream of Glen Canyon Dam) is the starting point, as RM 0, with mileage measured for both upstream (-) and downstream directions.

Stability of Nearshore Habitats

Constant and low discharge might benefit fish by stabilizing nearshore habitats, if, for example, daily fluctuations in discharge, stage, and/or velocity makes foraging/feeding less profitable relative to when discharge is stable (for example, more energy is expended foraging during fluctuations). The 2000 low summer steady flow experiment (constant discharge of 8,000 cfs from June through August) warmed and stabilized nearshore environments (B. Ralston, U.S. Geological Survey, written commun., 2009), but there is no evidence that this management action is responsible for the decade-long increasing trend in adult humpback chub (Coggins and Walters 2009). The Grand Canyon humpback chub population began its current uptick as the result of increasing recruitment of the cohorts spawned after about 1998. Inferences with respect to the native fish response to the 2000 experiment are weak because of reduced sampling efforts in the years before 2000 and low numbers of native fish present in the system in 2000, limitations that reduce the statistical power of comparisons that were made (B. Ralston, U.S. Geological Survey, written commun., 2009). Further, no process-level measurements of fish growth, such as otolith daily increments or RNA/DNA ratios, were made during this experiment, so the fish response was only evaluated by comparing catch rate data in 2000 with the years before and after, and by comparing the strength of the 1998–2000 cohorts after they recruited into the adult population relative to the strength of cohorts from years before or after.

There was no clear response of biological parameters to short-duration flow treatments that were implemented in 2005. During September and October 2005 fluctuating (7,000 to 9,000 cfs) and steady releases (8,000 cfs) were alternated on 2-week intervals. Backwater and mainstem habitats throughout the Colorado River ecosystem were sampled for water-quality parameters, invertebrate biomass, and fish relative abundance in early September (fluctuating) and again in late September (stable). Turbidity, which is negatively related to primary production, was significantly lower during the steady discharge treatment, but this decrease was likely because of tributary spates during the fluctuating treatment rather than the stable discharge treatment itself. Zooplankton concentrations were higher during the fluctuating treatment while relative abundance of bluehead suckers (*Catostomus discobolus*) was higher during the steady treatment. There were no statistically significant differences across flow treatments for biomass of the 11 benthic macroinvertebrate taxa collected, and there were no treatment effects on the relative abundance of the other 10 fish species collected (Ralston and others, 2007). This sampling effort was not repeated during the second pair of fluctuating-stable discharge treatments that occurred in October 2005, so it is tenuous to ascribe the differences that were observed in biological parameters to the flow treatments. Further, no process-level measurements, such as rates of primary production or fish growth, were made during this experiment.

Juvenile humpback chub catch rates measured by the nearshore ecology project's pilot study in August 2008 during fluctuating flows were higher relative to catch rates from September 2008 during steady flows. However, large numbers of humpback chub, especially 2- and 3-year-old fish, were captured on both trips, likely because of flooding in the Little Colorado River from July to September that moved humpback chub into the mainstem (discharge of the Little Colorado River at Cameron, Arizona, was above 1,000 cfs for a duration of least 2 days on five different occasions from July to September 2008). Little Colorado River spates, which periodically move humpback chub into the mainstem, will likely complicate interpretation of catch rate/abundance data collected by the nearshore ecology project throughout the remainder of the FSEF.

Otolith (inner ear bone) data highlights the importance of using process-level measurements to document biological responses to the FSEF. Korman and Campana (2009) found that steady flow releases conducted 1 day/week (Sunday) in January through March of 2003 through 2005 led to measurable increases in growth (presumed to correlate with measured otolith responses) of young-of-year rainbow trout (*Oncorhynchus mykiss*) below Glen Canyon Dam. Because this was documented in the Glen Canyon Dam tailwaters reach (RM 0 to -15) in winter when nearshore temperatures were likely no different from the mainstem, this study indicates that stability of nearshore habitats without concomitant warming can benefit rainbow trout. It is possible that steady flows in September and October, a time when nearshore warming is likely modest, will also benefit juvenile humpback chub simply by stabilizing nearshore environments. However, results obtained from trout may not be directly comparable to other fishes, including humpback chub.

Food Resources

Constant discharge will increase available food resources if algae and invertebrate growth rates are higher when discharge is constant or if accumulation of algae and invertebrate biomass is higher during steady flows relative to fluctuating flows (Production is total biomass accumulation per unit time, P=Growth Rate*Biomass). The two most likely mechanisms whereby stable discharge could increase algae and invertebrate growth rates are through (1) warming nearshore habitats and/or (2) delivering nutrients to algae and food particles to invertebrates should constant water velocities support higher growth rates relative to water velocities that fluctuate on a daily basis. Experiments at the Artificial Stream and Pond Research Facility at the Loyola University Chicago directly evaluated these two mechanisms and found strong support for mechanism 1 (temperature), but results were actually contrary to mechanism 2 (stable water velocity) (Kennedy and others, U.S. Geological Survey, written commun., 2009).

Net primary production of Colorado River algae and individual growth rates of larval black flies were more than twice as high in 15ºC streams relative to 10ºC streams, indicating minor increases in the amount of nearshore warming (that is, 5ºC) can lead to substantial increases in algae and invertebrate growth rates (see figs. 1a and 2a). In contrast, net primary production was about 50 percent lower in streams with constant daily velocity (15 cm/second) relative to streams with either low (velocities of 22 to 44 cm/second within a day) or high daily velocity fluctuations (11 to 67 cm/second within a day; see figs. 1b and 2b). Individual growth rates of larval black flies were lowest in the stable flow streams on the two occasions these measurements were made, but the differences were not statistically significant. There were no significant interactions between water velocity and temperature for any of the response variables evaluated. Growth and production in stable flow streams was likely lower than fluctuating streams because the rate of nutrient and food delivery was lower in stable streams. That is, the water velocity of the stable treatment streams was lower than the average water velocity of fluctuating treatment streams. This aspect of the experimental design is similar to the FSEF, with stable discharge (velocity) in September and October being lower than discharge (velocity) in July and August. It should be noted that the water velocities evaluated are lower than reach-average velocities in the Colorado River. Regardless, these results indicate water temperature has a strong and positive effect on algae and invertebrate growth rates while stable water velocities do not (Kennedy and others, U.S. Geological Survey, written commun., 2009).

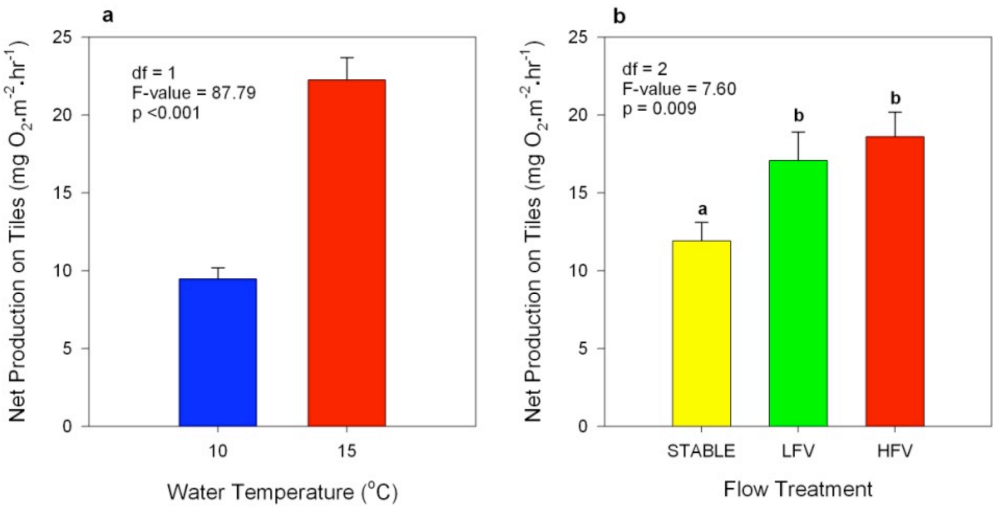

Figure 1. The effect of water temperature (a) and flow treatments (b) on net production. LFV = Low Fluctuating Velocity and HFV = High Fluctuating Velocity. Different letters above bars in panel b denote significant differences among treatment levels based on Tukey's HSD test. Data are preliminary and have not been peer-reviewed.

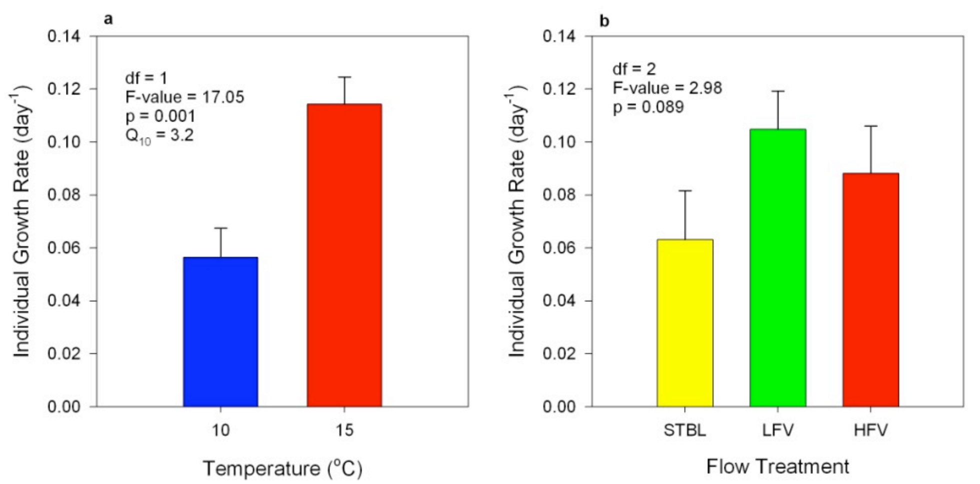

Figure 2. The effect of Water Temperature (a) and Flow Treatments (b) on the Individual Growth Rates of black fly larvae. LFV = Low Fluctuating Velocity and HFV = High Fluctuating Velocity. Black flies were left in streams for 10 days. Data are preliminary and have not been peer-reviewed.

Accumulation of algae and invertebrate biomass might be higher during steady flows if rates of sloughing and downstream export are higher when discharge is fluctuating. However, rainbow trout and humpback chub have been documented to forage on drifting food items (Valdez and Ryel, 1995; McKinney and Speas, 2001), so increases in benthic biomass because of a decrease in sloughing may actually reduce the quantity of drifting food items that are available to these species. Benthic biomass data are inherently variable (Stevens and others, 1997) and it seems unlikely that 2 months of steady flows in the fall, a time when primary production is decreasing and steady-flow mediated increases in nearshore warming are likely minimal (Korman and others, 2006), will lead to a detectable accumulation of algae or invertebrate biomass. However, algae and invertebrate drift data are less variable and easier to collect than benthic biomass data, so we propose evaluating drift response to the FSEF and using these data to make inferences about potential biomass accumulation.

Experimental Design

Fall Steady Flows

Selecting a discharge for the FSEF and determining whether discharge should vary across years of the experiment depends on what science questions are of greatest interest to managers. Our assumption is that managers are most interested in determining whether steady flows in the fall have a positive impact on the recruitment of juvenile humpback chub into the adult population. Varying the discharge of stable flows across years would allow scientists to evaluate whether discharge volume affects the degree of nearshore warming or habitat selection by juvenile humpback chub. However, identical steady discharge across the remaining years of this experiment would simplify interpretation of humpback chub recruitment data. That is, having the same stable discharge across the remaining years of the experiment would make it easier for scientists to attribute any trends in humpback chub recruitment observed in subsequent years to the steady flow experiment.

We believe managers are also interested in maximizing the amount of backwater habitat available during the steady flows, and recently published findings based on data collected in 2008 demonstrate that there is generally greater abundance of backwater habitat at lower flows (Grams and others, 2010). In October 2008, there was about 26 percent greater area of backwater habitat at 10,000 cfs than at 12,000 cfs and an additional 50 percent more habitat at 8,000 cfs than 10,000 cfs. Based on these results, there may be reason to implement the lowest possible discharge of 8,000 cfs, if there is a desire to maximize the quantity of backwater habitat. It is important to recognize that the amount of backwater habitat available in fall 2010 and thereafter will depend on the morphology of the sandbars that create the habitat. The results of Grams and others (2010) are based on morphology measured in October 2008 and, therefore, cannot be used to predict the amount of habitat that will be available. However, because the relation between habitat quantity and discharge was similar in February 2008, before the HFE, and October 2008, 6 months after the HFE, we believe that it is reasonable to assume that the relation will be similar in 2010 through 2012. In other words, we believe that there should still be more habitat at 8,000 cfs than higher discharges, even if the total amount of habitat is different in 2010 than it was in 2008. The only time the relation is expected to be different is for the first few months following a high flow, when backwater habitat size is not expected to vary as a function of discharge (Grams and others, 2010).

If water releases must be moved into other months of the year to accommodate these steady flow levels, then it is recommended that releases in July and August not be increased, as daily peak discharges during these months are already relatively high. Further increases will increase sediment transport and sandbar erosion, an undesirable side effect because it would reduce backwater area.

August to September Transition in Discharge

Determining whether the transition from the high discharges of August to lower discharges of September has a negative impact on organisms downstream is of longstanding interest to managers. The BO calls for study of this topic, stating the following:

> …transitions from August to September in some years have consisted of a transition from a lower limit of 10,000 cfs in August to an upper limit of 10,000 cfs in September. Such a transition results in a river stage level that is below the varial zone of the previous month's flow, and may be detrimental to fishes and food base for fish. Reclamation has committed to adjusting daily flows between months to attempt to attenuate these transitions such that they are more gradual, and to studying the biological effects of these transitions, in particular to humpback chub.

However, studying potential effects of these transitions on food base or fish would require a series of experimental transition flows that would confound and complicate interpretation of data from the ongoing FSEF. Previous research on stranding in Grand Canyon, which was conducted during the 1980s when daily changes in discharge were much greater than presently allowed (that is, change from 25,000 to 5,000 cfs in roughly 6 hours), revealed that only a small percentage of backwaters contain isolated pools when discharge is drastically reduced over a short time period (Maddux and others, Arizona Game and Fish Department, written commun., 1987). Humpback chub (0.2 percent) and native fishes collectively (4 percent) represented a small percentage of the 1,923 fish that were stranded in isolated pools during a systemwide survey conducted from October 19–21, 1984 (Maddux and others, Arizona Game and Fish Department, written commun., 1987). The average size of native fish stranded was also small (<55 mm), indicating that adult native fish are not susceptible to stranding. The GCMRC has concluded that the comprehensive study by the Arizona Game and Fish Department (Maddux and others, Arizona Game and Fish Department, written commun., 1987) provides sufficient information for managers to make an informed decision about whether transitions should be gradual (to reduce potential stranding of native fish) or if transitions can be abrupt (because changes in monthly volume are much more gradual now than during Maddux study). As a result, the GCMRC concludes that additional study of stranding is not warranted.

If managers are interested in studying the effects of abrupt transitions in monthly volume on food base or fish growth, the GCMRC is ready to help design the necessary experimental hydrographs. But any transition experiments and associated studies should be conducted after 2012 when the FSEF will be completed. Conducting this research after 2012 would allow transition studies to benefit from the experience and insights gained by FSEF studies (that is, what techniques worked, whether process-level measurements sensitive enough to detect transition effects, etc.). Further, designing transition experiments would not be constrained by the ongoing FSEF.

High-Flow Experiments

The number and size of backwaters has greatly diminished since the March 2008 HFE (T. Kennedy, U.S. Geological Survey, personal observations, 2008, 2009). In April 2008, immediately after the HFE, there were at least six large backwaters between the Little Colorado River and Lava Chuar (the reach for the nearshore ecology project), and they were all present across the full range of April flow fluctuations. A year later, there was only one backwater in this reach that was present across the full range of flow fluctuations in July 2009 (M. Yard, U.S. Geological Survey, personal observations, 2009). There are three other backwaters in this reach, but they are only isolated during the night when discharge is low; however, during the day when discharge is high, the return-current channel bar is overtopped. As such, the nearshore ecology project is evaluating the interactions between flows, fish growth, and habitat type in a reach where the amount of backwater habitat is minimal. If managers are interested in having more and larger backwaters available for the nearshore ecology project to evaluate, a HFE could be conducted should the sediment trigger be reached before October 2011, when fieldwork for the nearshore ecology project is scheduled to end. We propose consulting with Reclamation on this issue in early 2010 after the results of the March 2008 HFE have been reported and the effects of experiment on backwater habitat are known.

Ongoing and Proposed Studies

Objectives

Collectively, the studies we describe in the next section will evaluate the components and linkages of the Colorado River ecosystem that managers are most interested in evaluating with respect to stable discharge (see especially daily flow variation and nearshore habitat stability components of fig. 3). These studies are as follows:

1. Nearshore ecology project (see appendix A for the complete project description)
2. Stock assessment of Grand Canyon native fish
3. Aquatic food base monitoring
4. Rainbow trout monitoring
5. Supplemental water-temperature data collection
6. Ecosystem modeling efforts

Projects 1 through 5 emphasize process-level measurements because previous studies focusing on static measurements, with the exception of HFEs, have had minimal success detecting impacts of short-duration flow experiments (that is, fall steady flow experiments of 2005, see Ralston and others, 2007). Finally, under Project 6, ecosystem-modeling efforts will incorporate much of these data and allow for comparison with different flow scenarios.

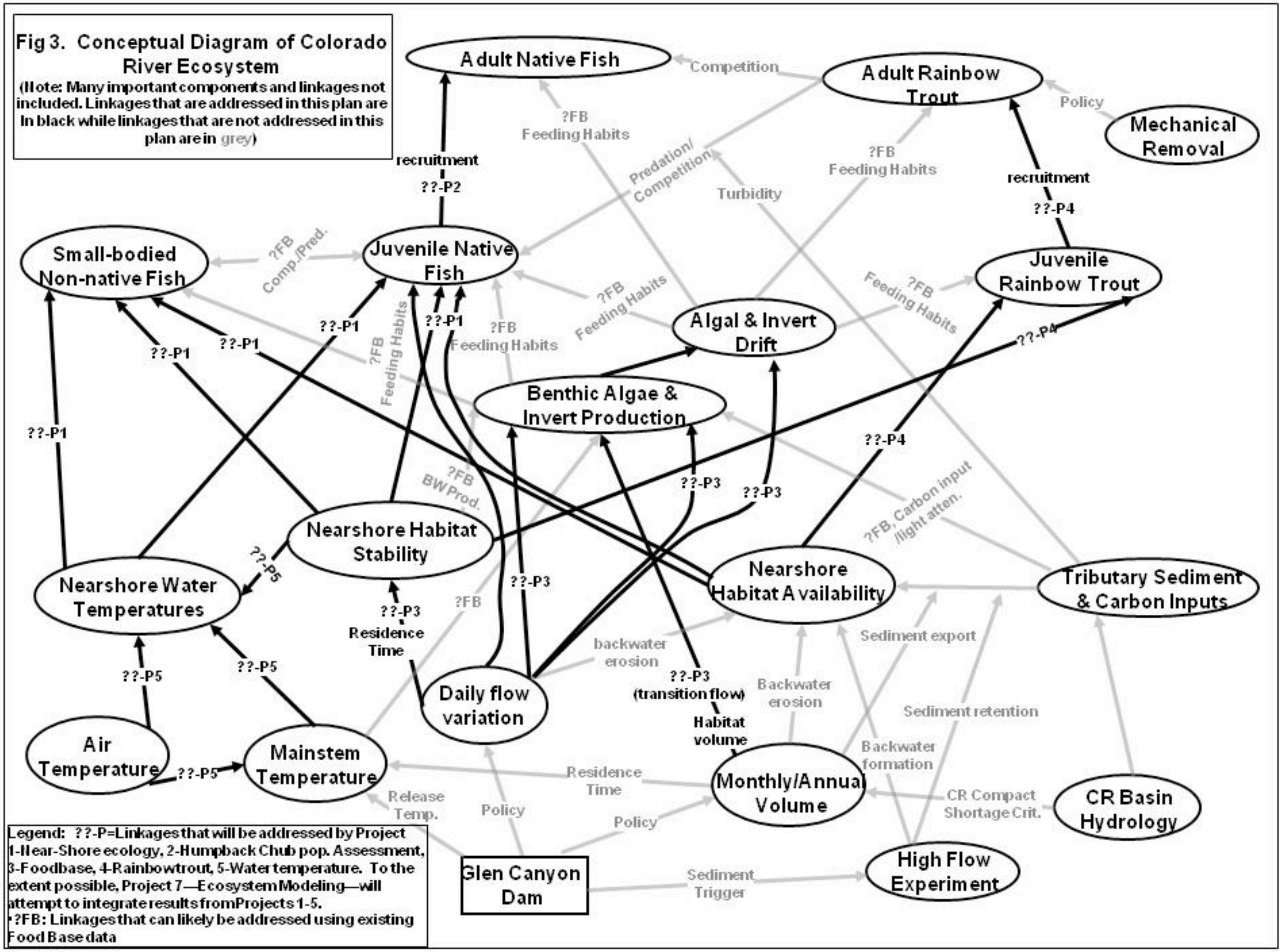

Fig 3. Conceptual Diagram of Colorado River Ecosystem

(Note: Many important components and linkages not included. Linkages that are addressed in this plan are In black while linkages that are not addressed in this plan are in grey)

Data Synthesis and Integration

We will use several lines of evidence to determine whether humpback chub benefit from stable flows in September and October because of the significance and importance of this issue. Over the next 5 years, there will be hourly variation in flow rates (related to diel variations in energy demand) during summer months (modified low fluctuating flows, MLFF, June through August) and lower, steady experimental flows during the fall (FSEF, September and October).

The centerpiece of this data synthesis and integration is the nearshore ecology project (Project 1), which seeks to determine the use and relative importance of nearshore habitat to humpback chub and other fishes and addresses strategic science questions (SSQs) 1.1, 1.7, 4.2, 5.4, and 5.6. This project will quantify abundance, survival, habitat use, growth, and natal source of selected native and nonnative juvenile fish over two flow periods (summer MLFF and FSEF). This project will evaluate humpback chub response by measuring differences in static measurements (catch rate, abundance, and occupancy data) and process-level measurements (proxies for fish growth—otolith daily increments, RNA/DNA ratios) during fluctuating flows of July and August relative to these same measurements during stable discharge in September and October. These measurements will evaluate the short-term effect of interactions between flow, fish habitat selection, and growth, and will help inform analysis of humpback chub recruitment trends. Because of the importance of the nearshore ecology project, a complete project description is presented in appendix A.

If stock-assessment analysis (Project 2) finds that humpback chub recruitment trends from cohorts spawned during 2008 through 2012 are strongly positive, this may provide support that steady flows in September and October benefit humpback chub. During the remaining years of the experiment there are likely to be differences in annual volumes, tributary activity, and other factors that will affect humpback chub recruitment success and may confound data interpretation. As such, we propose that the same stable discharge occur the remaining years of the experiment to minimize the number of confounding factors that will complicate interpretation of these recruitment data. We are not evaluating interactions between native and nonnative fish (that is, competition and predation) because previous studies have evaluated these interactions (Yard and others, in press; Kennedy and others, U.S. Geological Survey, unpub. data, 2010), and we do not expect there to be a strong interaction between the proposed July–October flows and competition or predation. Yard and others (in press) found turbidity had a strong influence on the degree of piscivory by rainbow trout, and tributary activity will have a far greater impact on turbidity than steady flows. Further, the nearshore ecology project pilot study attempted to quantify differences in predation risk among habitat types and across flows in August and September 2008, but the results were inconclusive and the work was extremely time consuming. Thus, our humpback chub projects focus on studying the short-term interactions between flows, habitat use, and fish growth, and the long-term effect of these interactions on recruitment.

Food base data (Project 3) will provide additional insights into mechanisms underlying any native fish response and seeks to determine whether and to what degree flow regimes impact the rates of primary production and/or invertebrate drift. Project 3 specifically relates to SSQ 3.5. The food base project focuses on process-level measurements at locations that are easy to access (Lees Ferry and Diamond Creek). Frequent measurement of these parameters, which is only possible at easy to access locations, will greatly increase the strength of our inferences with respect to flow. Work in Lees Ferry will be especially informative because tributary sediment and carbon inputs, which have a far greater impact on algae production and organic drift than do the proposed flows, are minimal in this reach. We are not proposing food base data collection in association with the nearshore ecology project because fieldwork for food base was reduced starting in 2009 to complete sample processing, data analysis, and reporting.

Monitoring of rainbow trout populations (Project 4) will provide insights into the impacts of flow on fish and addresses, in part, SSQs 3.6, 4.2, 5.4, and 5.6. Work by Korman (Gloss and Coggins, 2005; Korman and Campana, 2009) has provided the most conclusive evidence to date of the relationship between dam operations and fish vital rates (that is, growth and survival). Frequent and low-cost measurements, and the lack of tributary activity and other complicating factors, make it easier to identify the nature of flow/trout interactions in Lees Ferry relative to sites downstream. This work will be continued because understanding the rainbow trout response to experimental flows will help inform scientists about native fish response at downstream locations, where tributary activity will make it harder to separate the effects of flow.

We propose additional water temperature data collection (Project 5) because one of the primary mechanisms whereby stable flows might benefit native fish is by increasing nearshore warming. This project is not in GCMRC's fiscal years 2010 to 2011 work plan and would require supplemental funding. These data will be critical for evaluating the degree of nearshore warming that occurs with stable flows across summer and fall and for informing analysis of native fish growth rates among habitat types.

Finally, we propose that ecosystem-modeling efforts (Project 6) underway in 2011 and 2012 will include data analysis methods and integration of physical and biological research data into models for response of aquatic ecosystem indicator variables to possible management actions. The goal of this modeling effort is to provide screening of alternative adaptive management proposals for improving responses of performance indicators such as abundance of humpback chub. These models are likely to be developed in an Ecopath with Ecosim (EwE) platform in cooperation with Carl Walters (University of British Columbia) and Josh Korman (Ecometric Research, Inc.). We believe that this project provides a good framework for separating the effects of flow from other variables such as nonnative fish abundance, changes in food resources, or tributary hydrology.

The ecosystem modeling effort will focus and integrate key SSQs and Science Advisor (SA) questions, including indentifying linkages between food web changes and fish population changes in response to flow actions below Glen Canyon Dam:

> **SSQ 3-5** How is invertebrate flux affected by water quality (for example, temperature, nutrient concentrations, turbidity) and dam operations?
>
> **SA 1** What are the most limiting factors to successful HBC adult recruitment in the mainstem: spawning success, predation on YoY and juveniles, habitat (water, temperature), pathogens, adult maturation, food availability, competition?

In addition, modeling efforts will address responses of native fish to mechanical removal of nonnative fish, fall steady flows, and backwaters created by experimental high flows:

SSQ 1-2 Does a decrease in the abundance of rainbow trout and other cold- and warmwater nonnatives in Marble and eastern Grand Canyons result in an improvement in the recruitment rate of juvenile HBC to the adult population?

SSQ 5-1 How do dam release temperatures, flows (average and fluctuating component), meteorology, canyon orientation and geometry, and reach morphology interact to determine mainstem and nearshore water temperatures throughout the CRE?

Development and testing of EwE models for food web interactions in the aquatic communities will occur in the Lees Ferry and Little Colorado reaches of Grand Canyon. This will involve continued development and fitting to historical abundance trend data of EwE models developed during FY2009 in cooperation with GCMRC scientists. Model parameter estimates will be refined using information provided by GCMRC cooperators, and formal parameter estimation procedures will be applied to estimate key production parameters by fitting the models to historical fish population trend data for 1990 through 2009.

The Grand Canyon Ecosystem Model (GCEM), developed in the late 1990s through collaboration between Ecometric Research and the GCMRC (see Walters and others, 2000), will be used to reconstruct historical changes in the Colorado River food base for native and nonnative fish associated with changes in diurnal flow regimes and turbidity conditions caused by tributary sediment inputs. The EwE food web models need to be fitted to historical abundance trend data, and that model fitting will be misleading unless the EwE models are provided with realistic time forcing data on past changes in primary and secondary (insect, amphipod) production owing to change in turbidity. The GCEM model will be run with historical tributary sediment inputs and refined estimates of regrowth rates of primary producers following periods of low productivity because of high turbidity to provide monthly estimates for 1990 through 2009 of food biomass likely to have been available to native and nonnative fish in reaches of Grand Canyon near and below the Little Colorado River.

Ongoing collaboration with University of Florida and State University of New York at Syracuse will evaluate pilot study results from flannelmouth sucker (*Catostomus latipinnis*) otolith analyses and employ geochemical signatures in water and native fish otoliths to infer natal origin, tributary habitat use, and migration patterns. The project will conduct pilot analyses of flannelmouth sucker otoliths and water samples collected in fiscal year 2008. Preliminary analyses of the water samples suggest promising uniqueness among Colorado River tributaries for describing patterns in flannelmouth sucker otoliths associated with ontogenetic shifts in tributary versus Colorado River occupancy. These analyses above will tie into the nearshore ecology project with the objective of troubleshooting field methods and data analysis procedures, with particular emphasis on assessment of changes in native fish dispersal and survival rates in relation to changes from fluctuating to fall steady flows.

Reporting and Synthesis

Results of individual projects will be presented in the various reports or publications that are listed in each project description. We will also produce an overall summary report to be delivered by January 2013 that summarizes and synthesizes the results of all projects with respect to the FSEF. The cost to produce this report (workshop with relevant scientists and managers, 2 to 3 months salary for one GS-12 to GS-14 scientist to lead writing, and publication costs) is estimated to be about $50,000.

Proposed Studies

Project 1—Nearshore Ecology (Bio 2.R15.09)

Start Date

October 2008

End Date

September 2012

Principal Investigators

W.E. Pine, III (University of Florida), J. Korman (Ecometric Research, Inc.), K. Limburg (State University of New York, Syracuse), M. Allen (University of Florida), T.K. Frazer (University of Florida), in cooperation with M.D. Yard, L.G. Coggins, Jr., and C.J. Walters (GCMRC)

Geographic Scope

The mainstem Colorado River in Grand Canyon below the mouth of the Little Colorado River.

Project Goals

The primary goal of the nearshore fish ecology study is to relate river flow variables and ecological attributes of nearshore habitats to better understand the relative importance of the biotic and abiotic attributes of these habitats to juvenile (less than 200 mm total length) native and nonnative fishes.

The fall steady experimental flow (FSEF) related objectives that are addressed by this project are:

- Develop sampling approaches and analytical methods to use for determining abundance, density, or occurrence of native and nonnative fishes among different nearshore habitat types.
- Assess past and current data and integrate data across multiple sources and disciplines to determine small-bodied and juvenile fish nearshore habitat selection at local, geomorphic, and landscape scales.
- Determine whether discharge regime (i.e., fluctuating vs. steady discharge) affects nearshore habitat selection, movement, growth, and survival of native and nonnative fishes.

Need for Project

The life history requirements of HBC in the mainstem Colorado River are not well understood. Habitat selection by HBC and whether those habitats are affected by dam operations are of particular interest to the GCDAMP and managers. To help meet these information needs, this project will determine whether native fish vital rates (i.e., survival and growth) differ among habitat types and/or flow regimes. Findings from this project will provide information on native fish habitat requirements and guide future GCDAMP recommendations for the Department of the Interior to consider as management or experimental actions.

Strategic Science Questions

Primary SSQs addressed:

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 4-2 How important are backwaters and vegetated shoreline habitats to the overall growth and survival of YoY and juvenile native fish? Does the long-term benefit of increasing these habitats outweigh short-term potential costs (displacement and possibly mortality of young humpback chub) associated with high flows?

SSQ 5-4 What is the relative importance of increased water temperature, shoreline stability, and food availability on the survival and growth of YoY and juvenile native fish?

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?

Information Needs Addressed

RIN 2.1.3 What is the relationship between size of HBC and mortality in the LCR and the mainstem? What are the sources of mortality (that is, predation, cannibalism, other) in the LCR and the mainstem?

RIN 2.1.4 What habitats enhance recruitment of native fish in the LCR and mainstem? What are the physical and biological characteristics of those habitats?

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 4.2.6 To what extent are RBT below the Paria River predators of native fish, primarily HBC? At what size do they become predators of native fish, especially HBC, that is, how do the trophic interactions between RBT and native fish change with size of fish?

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 12.9.1 What is the impact on downstream resources of short-term increases to maximum flow, daily fluctuations, and downramp limits?

RIN 2.6.6 How is the rate of mortality for flannelmouth sucker, bluehead sucker, and speckled dace in the Colorado River ecosystem related to individual body size? What are the sources of mortality for flannelmouth sucker, bluehead sucker, and speckled dace in the Colorado River ecosystem?

RIN 4.2.5 To what extent is there overlap in the Colorado River ecosystem below the Paria River of RBT habitat and native fish habitat?

RIN 7.4.1 What is the desired range of seasonal and annual flow dynamics associated with powerplant operations, BHBFs, and habitat maintenance flows, or other flows that meet GCDAMP goals and objectives?

EIN 2.1.1 How does the abundance and distribution of all size classes of HBC in the LCR and mainstem change in response to an experiment performed under the Record of Decision, unanticipated event, or other management action?

EIN 2.1.2 How does the year class strength of HBC (51 – 150 mm) in the LCR and mainstem change in response to an experiment performed under the Record of Decision, unanticipated event, or other management action?

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?

EIN 2.6.1 How does the abundance, distribution, recruitment and mortality of flannelmouth sucker, bluehead sucker and speckled dace populations in the Colorado River ecosystem change in response to an experiment performed under the Record of Decision, unanticipated event, or other management action?

SIN 8.5.4 What is the role of turbidity and how can it be managed to achieve biological objectives?

Methods and Tasks

The nearshore ecology study will incorporate findings from ongoing studies and develop new sampling and analytical approaches that examine the effects of the March 2008 high-flow experiment on nearshore habitats and address the effects of modified low fluctuating flows (MLFF), including September–October fall steady experimental flows (FSEF), on juvenile HBC and other native fishes. The specific methods that the cooperator will use to address these issues are:

1. Investigate sampling methods to estimate fish habitat use, growth, and survival. Estimation of juvenile abundance, survival rate, growth rate, and habitat use is fundamental to resolving uncertainties in the conceptual model and the two key research questions outlined and identified above. We propose sampling trips in late July and late August to characterize abundance, habitat use, growth, and survival rate of juvenile fish over the summer under MLFF flow fluctuations. These trips would be followed by sampling trips in early September and late October to characterize juvenile fish responses during the MLFF-FSEF transition, and FSEF period. Differences in abundance in each habitat type, between each sampling trips would be used to estimate habitat specific, reach-wide survival rates across flow events. We propose two basic sampling approaches for estimating these characteristics: (1) reach-wide abundance estimation (RWAE); and (2) robust-design mark-recapture (RDMR) at replicate sites.

2. Site selection. We will use existing data and models from the GCMRC physical science program to quantify habitat availability over the study reach that contains the RDMR sites, habitat availability within the sites, and how habitat changes with flow. The existing GCMRC shoreline

GIS database and other surveys will be used to stratify habitat into classes such as talus slopes, open sand bars, vegetated sand bars, cobble bars, and backwaters. We hypothesize that unstable habitat types (sand bar-mediated backwaters) will be used only minimally during the summer-unsteady flow period, but that use of these habitats will increase during the fall-steady period when flows are stabilized. If this difference in habitat use were ecologically important, we would also predict increase in growth and survival during the fall-steady flow period relative to the summer because habitats may offer more favorable conditions, such as food and higher temperature.

3. Effects of Fall Steady Flows on Native Fish Habitat Use. Any mark-recapture approach to estimating abundance and density depends on recapturing sufficient numbers of marked individuals to draw inferences on the parameters of interest. Closed population models generally have fewer parameters (and assumptions) than open models and are thus better able to estimate parameters of interest (capture probability and abundance) when recaptures are low. We will evaluate the closure assumption in our mark-recapture experiments using methods similar to Korman and others (2009). Additionally, recaptures of fish marked on previous trips will provide useful information on growth and movement (e.g., movement into backwaters during periods of steady flow) between sampling trips and associated flow conditions. The nearshore ecology project pilot sampling data from 2008 should provide some information on closure and also provide information on capture probability which is necessary to fully assess how violation of the closure assumption biases abundance estimates. This project will evaluate occupancy models (MacKenzie and others, 2005) and sonic tags to support habitat use assessment. This project will utilize otoliths (inner ear bones) from native fishes, such as flannelmouth sucker and humpback chub to investigate habitat use and origin of fish by using microchemistry to identify unique isotopes. Otoliths may also prove useful for determining growth and survival rates of humpback chub and other fishes.

Links/Relationships to Other Projects

This project utilizes habitat information developed largely by the GCMRC Physical Sciences and Modeling and the Data Acquisition, Storage, and Analysis (DASA) programs. The results of this project will help evaluate responses of small size classes of fish to various dam release flows, and so will provide some of the information needed to assess the status and trends of humpback chub in the mainstem Colorado River.

Logistics

This project will utilize four trips, one each in July, August, September, and October, for three years (2009-2011), subject to permit approval. All four trips are to be motor supported. The first three are scheduled to launch in the motor season, but the October trip will require authority from Grand Canyon National Park to use motors during the non-motor season. Sampling in October supports investigation of the possible effects of steady flows on fish habitat use and so authority to conduct the trip has been requested.

Products/Reports

Annual reports of project results will be delivered in December 15 of each year of the fieldwork, 2009-2011. A final, synthetic report will be delivered by September 2012.

Budget

FY 2010: $552,825
FY 2011: $556,911

Project 2—Stock Assessment of Grand Canyon Native Fish (BIO 2.R7.10–11)

Start Date

2007

End Date

Ongoing

Principal Investigators

Fisheries Biologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center, and C.J. Walters, University of British Columbia

Geographic Scope

Colorado and Little Colorado Rivers in Glen, Marble, and Grand Canyons

Project Goals

This project will provide annual updates of size composition and capture rates of humpback chub (HBC) and other Grand Canyon fish to the Glen Canyon Dam Adaptive Management Program (GCDAMP) and other managers. Reporting will include retrospective time series to allow for comparison with previous years' data. The assembled HBC data from the Grand Canyon fish monitoring projects will be incorporated into updates of the Age-Structured Mark-Recapture (ASMR) model every 3 years (the next ASMR update will be published in 2012).

This project will lead the analyses of existing fish capture information recommended by the 2009 Protocol Evaluation Panel (PEP) for Grand Canyon Fishes. The goal of these analyses is to evaluate whether the fish monitoring project changes recommended by the PEP, especially to reduce some efforts and increase others, are consistent with the available data.

This project will seek to develop and implement methods for making the HBC database available electronically. Data serving must be done in a manner consistent with USGS Fundamental Science Practices.

Need for Project

Native fish populations in Grand Canyon are key resources of concern influencing decisions on both the operation of Glen Canyon Dam and other non-flow actions. To inform these decisions, it is imperative that accurate and timely information on the status of native fish populations, particularly the endangered HBC, be available to managers.

Several adaptive experimental management actions are being contemplated to better understand the mechanisms controlling the population dynamics of native fish and to identify policies that are consistent with management goals. The stock assessments generated from this project will support assessment of implemented experimental actions. This information is therefore crucial to

- inform the program as to attainment of identified goals,

- provide baseline status and trend information to be used as a backdrop to understand the mechanisms controlling native fish population dynamics, and
- evaluate the efficacy of particular management policies in attaining program goals. Finally, results from this project are potentially useful in assessing changes to Federal Endangered Species Act listing status of HBC in the Colorado River.

Strategic Science Questions

Primary SSQ addressed:

> **SSQ 1-1** To what extent are adult populations of native fish controlled by production of young fish from tributaries, spawning and incubation in the mainstem, survival of YoY and juvenile stages in the mainstem, or by changes in growth and maturation in the adult population as influenced by mainstem conditions?

Additional SSQ addressed:

> **SSQ 1-8** How can native and nonnative fishes best be monitored while minimizing impacts from capture and handling or sampling?

The Adaptive Management Program Science Advisors have articulated the following science question, which is partially addressed by this project:

> **SA 1** What are the most limiting factors to successful humpback chub adult recruitment in the mainstem: spawning success, predation on YoY and juveniles, habitat (water, temperature), pathogens, adult maturation, food availability, competition?

Information Needs

> **RIN 2.2.8** What combination of dam release patterns and nonnative fish control facilitates successful spawning and recruitment of humpback chub in the Colorado River ecosystem?

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

Methods and Tasks

To provide HBC status and trend information, the Grand Canyon Monitoring and Research Center (GCMRC) mark-recapture database will be annually updated with the most recent data collected during routine monitoring efforts including mainstem electrofishing and netting and the Little Colorado River monitoring efforts (see GCMRC/AMP 2011-12 work plan for additional details). Following this update, the HBC mark-recapture database will be reanalyzed using (where appropriate) both open and closed mark-recapture-based abundance estimators to provide the most current information on HBC status and trends. In particular, the ASMR models (Coggins and others, 2006a and 2006b; Coggins, 2007; Coggins and Walters, 2009) will be used to determine trends in HBC abundance and recruitment over multiyear time scales. Over annual time scales, this project will assemble and deliver summaries of annual catch rate and size-class composition of HBC and other species from the Little Colorado River (LCR) and mainstem to the GCDAMP and managers. It will also deliver other species metrics, likely to include results of closed population estimates and juvenile abundance from the LCR.

This project was reviewed by the 2009 PEP for Grand Canyon Fishes. The panel recommended that because of the inherent variability in the ASMR (for example, estimates of growth and mortality rates limit its ability to detect fine scale changes), preparing annual updates of the model was an inefficient use of personnel time, especially for the long-lived HBC. The PEP also observed that the ASMR has only limited sensitivity to detect small annual population changes, and that it requires tremendous personnel and computer resources to generate. Based on these observations, the PEP recommended that the ASMR be updated every 3 to 5 years. Because the GCMRC is planning to prepare the next *State of the Colorado River Ecosystem in Grand Canyon* (SCORE) report in FY2011, the GCMRC will accelerate this recommendation for the next iteration and include an update of ASMR in the FY2011 SCORE report. In the future, the GCMRC intends the next iteration of the ASMR following the FY2011 update will be scheduled for FY2014, consistent with the PEP recommendation. Updates will include not only estimates of HBC abundance and recruitment from ASMR, but also summaries of annual catch-rate and size composition estimates from LCR hoop net sampling, summaries of annual catch-rate and size composition estimates from mainstem Colorado River hoop and trammel net sampling, and closed population abundance estimates of HBC adults and rearing juveniles in the LCR as these data are available. Finally, the applicability of similar techniques to those described above will be evaluated to assess stocks of flannelmouth sucker and bluehead sucker.

The GCMRC fisheries biologist will work with agency and cooperative personnel to evaluate the utility of the remote passive integrated transponder (PIT) tag antenna project to provide information useful in determining movement rates of HBC into and out of the LCR, empirical capture probability estimates of LCR hoop het sampling, and PIT tag recapture information for inclusion in ASMR.

The 2009 PEP for Grand Canyon Fishes made a series of recommendations that direct shifting monitoring efforts to decrease efforts in the LCR and increase efforts in the mainstem of the Colorado River, subject to an analysis of the existing data to see if their recommendations are consistent with the data. The GCMRC fisheries biologist working on this project will be responsible for assembling and/or conducting the analyses necessary to evaluate the recommendations. AZGFD and USFWS personnel to support this effort will also conduct data analyses of individual projects. If the recommendations are found to be warranted, the shift to different monitoring will be initiated in FY2011; these projects are described elsewhere in Goal 2 of this work plan. If the data analyses are not found to support the recommendations, projects will revert to the work plans described for FY2010. The full analysis of all the data will not be required in FY2011, so there will be some shifting of the fisheries biologist time to other projects.

Links/Relationships to Other Projects

The status and trend of the Grand Canyon HBC population are two of the key metrics utilized in GCDAMP to evaluate the success of the GCDAMP and actions undertaken under the sponsorship of the GCDAMP. Therefore, annually updating the HBC catch rates and size-class composition and updating ASMR model runs every 3 years is related to many other GCDAMP work plan elements, especially experimental actions such as the March 2008 High Flow Experiment (described in a separate science plan) or removal of nonnative fish. The annual HBC population status will be important to projects studying biotic and abiotic aspects of the system—including the aquatic food base, riparian vegetation mapping, and nearshore ecology projects—because changes in the parameters measured by these projects can be compared to trends in the HBC population to search for relevant correlations.

Logistics

There are no logistical needs for this project.

Products/Reports

- This project will be the lead for retrospective analysis of the fish catch rate data, especially for HBC. The analyses will also be supported by AZGFD and USFWS personnel as part of the reporting for their respective projects. Under this project GCMRC will convene an annual fish meeting to review these analyses and see if the 2009 PEP recommendations are consistent with project changes in FY2011.
- The next scheduled update of the ASMR model will be in FY2011 to coincide with the next SCORE report, with the next update to occur in FY2014.
- Annual reports of the status and trends of HBC will be delivered to the GCDAMP committees by December 15 of each year. These updates will include summaries of annual catch-rate and size composition estimates from LCR hoop net sampling, summaries of annual catch-rate and size composition estimates from mainstem Colorado River hoop and trammel net sampling, and closed population abundance estimates of HBC adults and rearing juveniles in the LCR as these data are available.
- This project will pursue making the HBC data base information available electronically. This will be done in a manner consistent with USGS Fundamental Science Practices.

Budget

FY 2010: $110,877
FY 2011: $103,776

Project 3—Aquatic Food Base (Bio 1.R1 and 4)

Start Date

2006

End Date

2010

Principal Investigators

T.A. Kennedy (GCMRC), R. Hall (University of Wyoming), E. Rosi-Marshall (Cary Institute of Ecosystem Studies), and C. Baxter (Idaho State University)

Geographic Scope

Systemwide, from Glen Canyon Dam to Diamond Creek (RM 225)

Project Goals

The aquatic food base project will answer the following fall steady flow related questions:

1. Does flow regime affect rates of primary production or organic and invertebrate drift?
2. Does flow regime affect the residence time of water in backwater habitats?

Need for Project

After habitat, food is the resource that most often limits the distribution or abundance of animal populations (Krebs, 1994). Algae and aquatic invertebrates are two of the most common food types consumed by native and nonnative fish in the Colorado River (McKinney and Speas, 2001; Valdez and Ryel, 1995). Preliminary data indicate rates of algae drift are positively related to discharge, at least in Lees Ferry. Further, aquatic invertebrates in the Colorado River actually use filamentous algae as habitat (Shannon and others, 1994), so rates of invertebrate drift may also be positively related to discharge. If steady flows of low discharge decrease algae and invertebrate drift, then this could lead to an accumulation of algae and invertebrates on the river bottom. However, algae and invertebrate biomass data are extremely variable (Stevens and others, 1997), so it is unlikely that any observed changes would be statistically significant or could be ascribed to the short duration fall steady flows. The food base project has developed methods for quantifying algae production in the Colorado River using diel changes in dissolved oxygen concentration. Further, we have refined the invertebrate drift collection and sampling processing methods developed by McKinney and others (1999). Both of these process-based metrics (algae production, grams $O_2 \cdot m^{-2} \cdot d^{-1}$; invertebrate drift load, g $AFDM \cdot s^{-1}$) should be more sensitive to the subtle changes that are likely with fall steady flows compared to static measures of algae and invertebrate biomass (g $AFDM \cdot m^{-2}$).

The degree of nearshore warming appears to be related to the degree of isolation of those habitats from the mainstem river. Water temperature data indicate residence time of water in nearshore environments is greater when discharge is stable relative to fluctuating. However, the magnitude of this increase in residence time is uncertain. Water residence time in backwaters may also influence the productivity of these habitats because high residence time might allow for a water column food web to develop and might also allow for benthic algae and invertebrates to accumulate.

Strategic Science Questions

Primary SSQ addressed:

> **SSQ 3-5.** How is invertebrate flux affected by water quality (for example, temperature, nutrient concentrations, turbidity) and dam operations?

Information Needs Addressed

> **CMIN 1.5.1** Determine and track the composition and biomass of drift in the Colorado River in conjunction with measurements of flow, nutrients, water temperature, and light regime.

> **EIN 1.1.1** How does primary productivity in the reach between Glen Canyon Dam and the Paria River change in response to an experiment performed under the Record of Decision, unanticipated event, or other management action?

Methods and Tasks

Primary production is already being measured continuously in Lees Ferry and at Diamond Creek (RM 0 to 226). Primary production data collected during September and October 2008-2012 will be compared with the months before and after to determine whether steady flows affect rates of in-stream primary production. Organic and invertebrate drift is measured monthly at Lees Ferry. To determine whether steady flows affect drift rates we will compare data collected in September and October 2008-2012 with the months before and after. As part of the 1D funding, the food base project began intensive study of backwaters on their April 2008 river trip. Data being collected in backwaters includes primary and invertebrate production and dye-tracer studies to determine water residence time. Because data collection in backwaters began in April 2008, we do not have data on biological parameters from previous years to compare with 2008 fall steady flows data. However, water residence time will only be affected by the morphology of backwaters and the flow regime, but not season. Thus, we can determine whether steady flows affect water residence time in backwaters by comparing data collected during other flow regimes (i.e., April and June 2008 and January 2009). The food base project will launch a river trip in September 2009 to collect additional samples and water residence time measurements during the steady flow experiment.

Links/Relationships to Other Projects

Data from the food base project can be used to inform results of both rainbow trout monitoring and nearshore ecology projects. Although food base data collection will be focused on the Lees Ferry reach with less intensive data collection at Diamond Creek, our results should still be informative to the nearshore ecology project that is focused on the Little Colorado River confluence. Algae production and invertebrate drift are much higher in Lees Ferry than downstream reaches. In fact, algae production at downstream locations is essentially zero during times of high turbidity, and invertebrate drift measurements at Diamond Creek were largely discontinued because of extremely low invertebrate loads. Given the effects of the fall steady flows on food base components are likely to be subtle, we feel it is prudent to concentrate our efforts on the Lees Ferry reach because the higher food base abundance there makes it more likely that we will be able to detect treatment impacts. Even though food web structure in Lees Ferry is considerably different than around the Little Colorado River confluence, algae and invertebrates are important food items consumed by fish at both locations. Therefore, we feel conclusions and findings from our work in Lees Ferry can be used to inform results of the nearshore ecology study. In FY2011 the food base project will be implementing new monitoring protocols. If our work in Lees Ferry indicates fall steady flows are having a significant impact on the food base, we would expedite the implementation of these monitoring protocols around the Little Colorado River confluence.

Logistics

Logistics will be needed for monthly drift sampling at Lees Ferry and monthly maintenance of water quality sondes at Lees Ferry and Diamond Creek, as well as one river trip to study backwaters in September 2009.

Products/Reports

Publications

At least two peer-reviews journal articles that describe whether fall steady flows affected the food base will be produced as a result of this project. Tentative subjects for these publications include:

- Longitudinal and seasonal variation in algae production in the Colorado River
- Does flow regime affect rates of invertebrate drift in the Colorado River?

Reports

A brief report summarizing our findings with respect to the fall steady flows experiment will also be delivered at the conclusion of the project in September 2010.

Budget

Aquatic Food base (Bio 1.R1) FY10: $440,112
Aquatic Food base (Bio 1.R1) FY11: $207,200
Aquatic Food base Drift (Bio 1.R4) FY10: $56,260
Aquatic Food base Drift (Bio 1.R4) FY11: $0

Project 4—Monitoring Lees Ferry Fishes (Bio 4.M1.09)

Start Date

Ongoing

End Date

Ongoing

Principal Investigators

A.S. Makinster (Arizona Game and Fish Department), in cooperation with Josh Korman (Ecometric Research, Inc.) and GCMRC

Geographic Scope

Colorado River from Glen Canyon Dam to Lees Ferry

Project Goals

The fall steady flow related goals of this project are:

- Monitor the rainbow trout (RBT) recreational fishery between Glen Canyon Dam and the Paria River
- Monitor RBT redds and early life stages to support assessment of experimental flow releases from Glen Canyon Dam

This project is designed to monitor the status and population of this RBT fishery in response to management actions, and to determine how abundance, reproduction, survival, and growth are influenced by operations of Glen Canyon Dam, including fall steady flows. Trend analysis using indices of abundance can be used to determine whether changes in dam operations are having population-level effects on the fishery.

The 2009 Protocol Evaluation Panel (PEP) reviewed this project for Grand Canyon Fishes. The panel recommended that it was not cost effective or necessary to conduct multiple population monitoring and assessment trips each year to assess the Lees Ferry rainbow trout fishery. Rather, the panel recommended a single electrofishing trip at the randomized sites each year to physically observe the adult population and perhaps to tag fish if that was desired for more data collection. Analysis of this long-term dataset will be completed in 2009 to determine impacts of the recommended reduction in effort and the ability to meet management objectives.

The 2009 PEP did not recommend maintaining the monitoring of early life stages of rainbow trout that has been conducted for 5 of the last 7 years. However, this monitoring technique may be useful for studying the response of the fishery to experimental dam releases, and so it should be maintained through 2012 in response to the fall steady flow regime.

Need for Project

The Arizona Game and Fish Department (AZGFD) has managed the Lees Ferry recreational fishery since 1964. Lees Ferry serves as a popular destination fishery for international and national anglers. As such, it provides significant contributions to the Marble Canyon business community. The fishery is regulated by biotic and abiotic mechanisms that may in turn be affected by the operations of GCD. The monitoring of basic fish population elements, including abundance and distribution of native and nonnative fishes, provides the information necessary to assess the status of these resources and inform the Glen Canyon Dam Adaptive Management Program (GCDAMP).

Strategic Science Questions

Primary fall steady flow related SSQs addressed:

SSQ 3-6 What GCD operations (ramping rates, daily flow range, etc.) maximize trout fishing opportunities and catchability?

Methods and Tasks

Summary of annual monitoring/sampling:

- Two standardized random sampling surveys
- Two early life history trips (one or both may extend below the Paria River at RM 1)
- Creel surveys, funded by AZGFD

In monitoring, RBT are sampled using electrofishing to estimate biological parameters and to assess the status and trends of the fishery. This sampling design was developed to ensure managers have a monitoring program with the temporal “power” to detect population trends without biases in site selection, as well as a means to precisely estimate status of the rainbow trout population. Electrofishing provides information on size composition, relative abundance (catch per minute as an index of population size), condition (length-weight relationships), and disease. Electrofishing prior to 2010 occurred 3 times per year with sampling effort stratified over 27 random and 9 fixed sites. Present sampling design can detect a 6–10% linear change in abundance over a 5-year period. Work is currently underway to assess the statistical power of intra- and inter-annual comparisons.

Over the last 7 years a contractor, Ecometric Research, Inc., has been conducting surveys of RBT redds and early life stages of RBT in the Lees Ferry reach. These studies have been useful, especially in the analysis of dam operation impact to RBT. Similar studies may not be incorporated into long-term monitoring, but in light of the continued experimental operations of Glen Canyon Dam through 2012 the work is to be maintained, at least for FY 2010-11. In FY 2010-11 the AZGFD will work cooperatively with Ecometric, Inc. to transfer knowledge regarding the techniques and data analysis from the contractor to the agency, anticipating that AZGFD will be completely responsible for any early life stage monitoring that may be necessary in FY 2012 and beyond.

Links/Relationships to Other Projects

This project will help inform data on fish and habitat collected at downstream locations. Work by Korman (Gloss and Coggins, 2005; Korman and Campana, 2009) has provided the most conclusive evidence to date of the relationship between dam operations and fish vital rates (i.e., survival). Frequent and low-cost measurements, and the lack of tributary activity and other complicating factors, makes it easier to identify the nature of flow—fish interactions in Lees Ferry relative to downstream work. We will continue this work because the rainbow trout response to experimental flows will help inform native fish collected at downstream locations, where tributary activity will make it harder to separate the effects of flow.

Logistics

This project will field five trips annually:

- Two standardized random sampling surveys
- Two early life history trips (one or both may extend below the Paria River)
- One nonnative survey (may extend below the Paria River)

All trips are motor supported, launching from and returning to Lees Ferry just upstream of the mouth of the Paria River.

Products/Reports

Annual reporting of the results of all monitoring efforts will be delivered to GCMRC by December 15 of each year. AZGFD and GCMRC will be working together to develop additional peer-reviewed products documenting the status and trends of the Lees Ferry RBT fishery in FY 2010-11. These reports will include sections describing their findings with respect to impacts of fall steady flows on rainbow trout. AZGFD will be responsible for delivering analysis of the data from this project to fish cooperator meetings in calendar 2009 and beyond.

Budget

FY 2010: $207,858
FY 2011: $215,500

Project 5—Supplemental Water Temperature Data Collection

Need for Project

There is uncertainty regarding the degree of nearshore warming that will occur during the FSEF. Korman and others (2006) found that the amount of nearshore warming increased slightly in September relative to August, despite cooler air temperatures, because discharge volume and daily fluctuations were lower in September. No nearshore warming occurred in October because average daily air temperatures were comparable to water temperatures. However, temporal changes in nearshore warming may differ during steady flows relative to what Korman and others (2006) observed during fluctuating flows. The Physical Sciences and Modeling Program is developing a 2-D model that can be used to predict water temperatures in nearshore environments. But this model cannot be parameterized for steady flows in the fall because data are lacking. Detailed water temperature data will also be critical for interpreting data from the nearshore ecology project.

If steady flows in September and October 2008 through 2012 do not strongly benefit humpback chub, it may be because nearshore warming is minimal at this time of year. If this is the case, we suspect managers would consider evaluating steady flows during the summer months when there is greater potential for nearshore warming (Grand Canyon Monitoring and Research Center, 2008). Thermal infra-red imagery collected in June 2000 during the LSSF provide rigorous quantitative data on the degree of nearshore warming that can occur in June during steady flows of 8000 cfs. However, because these same data have not been collected during fluctuating operations at the same time of year, it is difficult to put these data into context. That is, it is unclear whether nearshore habitat with warm water temperature is gained during steady flows relative to fluctuating flows and if so, how much?

Scope of Work 1

We propose deploying arrays of water temperature thermistors below the Little Colorado River confluence (RM 61) from July 2010 through October 2010 in at least one of each of the different shoreline habitat types the nearshore ecology project is evaluating. In addition, we will deploy thermistors to monitor mainstem temperature at the upstream and downstream boundaries of the nearshore ecology study reach. These data would be used to determine the degree of nearshore warming that occurs during steady flows in September and October and also to parameterize and calibrate the 2-dimensional temperature model that the physical sciences group is developing. Deployment and maintenance of thermistors would be done in collaboration with the nearshore ecology project, as they will also be a primary user of these data. Thermistors would be deployed on the July 2010 nearshore ecology trip and retrieved on the October 2010 trip.

This project will also include analysis and reporting on mainstem and nearshore temperature data that were collected at up to 20 different locations from 2007 to 2010.

Budget

Biological Science Technician (GS-7-temporary): $20,000

Justification

Previous experience has demonstrated that maintaining thermistors during diurnal fluctuating flow dam operations requires a technician be onsite to visit the thermistor arrays at study sites every day. Deploying and maintaining thermistor arrays is outside the scope of work for the nearshore ecology project. Therefore, we propose hiring a 180-day temporary technician who would go on the nearshore ecology trips and deploy and maintain thermistors.

Scope of Work 2

We propose collecting thermal infrared imagery in June 2010 during fluctuating operations, so that managers can evaluate the increase in nearshore warming that occurs during summer steady flows. We also propose collecting these same data in late August during fluctuating operations and again in early September during steady operations to evaluate the magnitude of nearshore warming that occurs with steady flows in the fall. These data will help inform results of FSEF and also help inform discussions about future experiments that might include steady flows in the summer.

Budget

Acquiring thermal infra-red imagery for RM 30 to 72, the same reach that was covered in 2000, would cost approximately $35,000 per flight. Two weeks of Phil Davis' time would be required to process imagery from each flight (~$6,000/2-week pay period).

Project 6——Support and Enhancement of Ecosystem Modeling Efforts (R12.P1.10)

Need for Project

While a variety of experimental management policies have been implemented in recent years, analysis and communication of results and responses of indicators to policies have not been completed. More complete analysis and subsequent communication of the results of analysis (including modeling) will allow more effective selection of further experimental tests. For example, the LSSF flow experiment of summer 2000 was not fully evaluated until 2008, and likewise there have not been definitive reviews of all high-flow experimental results (1996 to 2008) or the effects of mechanical removal of nonnative fish, although the synthesis of flow tests and nonnative control analyses are now forthcoming. Such analyses have been hampered by confounding of multiple factors in causing changes (for example, temperature changes have made it hard to interpret fish responses to mechanical removal). Modeling tools provided by the Senior Ecologist (Walters) can help to at least clarify alternative hypotheses about the possible roles and relative importance of the factors.

Additional advancement of the flow and sediment elements of the existing GCEM is also planned as an additional element of the new Integrated Flow, Sediment, and Temperature Modeling research project (Wright and others in collaboration with Korman and Walters) as a further means of assessing fine sediment dynamics associated with various stakeholder planning needs and associated tasks tied to developing desired future conditions for GCDAMP goals.

Strategic Science Questions

The ecological modeling efforts will be directed at addressing priority AMWG questions, SSQs, and additional science questions (SAs) - provided by the Science Advisors (SA) in the integrated modeling efforts, as follows:

Abundance trends of rainbow trout 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?

This question also applies to future removal programs targeting other nonnative species.

> **SSQ 1-8** How can native and nonnative fishes best be monitored while minimizing impacts from capture and handling or sampling?

Abundance trends in native fish below the Lees Ferry reach:

> **SSQ 1-1** To what extent are adult populations of native fish controlled by production of young fish from tributaries, spawning and incubation in the mainstem, survival of young-of-year and juvenile stages in the mainstem, or by changes in growth and maturation in the adult population as influenced by mainstem conditions?

SA 1 What are the most limiting factors to successful humpback chub adult recruitment in the mainstem: spawning success, predation on young of year and juveniles, habitat (water, temperature), pathogens, adult maturation, food availability, competition?

SA 2 What are the most probably positive and negative impacts of warming the Colorado River on humpback chub adults and juveniles?]

Linkages between (productivity) food web changes and fish population changes:

SSQ 3-5 How is invertebrate flux affected by water quality (for example, temperature, nutrient concentrations, turbidity) and dam operations?

SA 1 What are the most limiting factors to successful HBC adult recruitment in the mainstem: spawning success, predation on YoY and juveniles, habitat (water, temperature), pathogens, adult maturation, food availability, competition?

Responses of native fish to mechanical removal of nonnative fish, fall steady flows, and backwaters created by experimental high flows:

SSQ 1-2 Does a decrease in the abundance of rainbow trout and other cold- and warmwater nonnatives in Marble and eastern Grand Canyons result in an improvement in the recruitment rate of juvenile HBC to the adult population?

SSQ 5-1 How do dam release temperatures, flows (average and fluctuating component), meteorology, canyon orientation and geometry, and reach morphology interact to determine mainstem and nearshore water temperatures throughout the CRE?

Using the new shifting rating curve method for routing suspended sand through the CRE, the project will produced advanced simulations for flow operations at Glen Canyon Dam and fate of tributary supplied sand inputs:

SSQ 4-1 Is there a "Flow Only" operation (that is, a strategy for dam releases, including managing tributary inputs with BHBFs, without sediment augmentation) that will rebuild and maintain sandbar habitats over decadal timescales?

Note: Results from element 5, will integrate suspended-sediment simulations with aquatic/fish simulations within the Ecopath with Ecosim (EwE) modeling being developed by Walters and others.

Links/Relationships to Other Projects

This project will uses data from all studies that collect information on the aquatic biota of Glen, Marble, and Grand Canyons, including the aquatic food web, HBC monitoring, Lees Ferry trout monitoring, mechanical removal, nonnative fish monitoring, and the nearshore ecology project. The main benefits to the projects listed will be to provide novel analyses of data and methods for linking project results into overall conceptual and quantitative models for response of the Colorado River aquatic ecosystem to management changes. The flow and sediment modeling elements of this project are linked most closely to the Integrated Flow, Sediment, and Temperature Modeling project.

Products/Reports

FY2010

- ChubIBM.exe computer program, narrative review for GCMRC fish scientists on probable biases and precision of future population estimates (Walters and others).
- Spreadsheets for use by GCMRC scientists in checking ASMR results from existing assessment programs, stock assessment report providing abundance trend estimates for sucker species (Walters and others).
- Revised flow and suspended-sediment submodel of the GCEM, including the recently innovated "shifting rating curve" for sand transport that will be reported by Wright and others (manuscript currently in preparation). This work is being integrated with ongoing modeling research funded in FY2010 (Wright and Korman).
- Ecopath with Ecosim Access database (mdb) with improved models and historical forcing data, including forcing time series data from updated GCEM, narrative report sections for use by GCMRC scientists in preparation of peer-reviewed papers on findings from the EwE models and GCEM/EwE model linkage (Walters and others).
- Senior Ecologist (Walters) will lead a science workshop for GCMRC scientists and cooperators in February/March 2010 to evaluate ecosystem model performance and produce a consensus scientific report on role of trophic interactions (food base changes, predator-prey interactions) in causing recent changes in native and nonnative fish abundances.
- Oral presentation (Walters) of the consensus ecosystem response report in a workshop/retreat for GCDAMP stakeholders (TWG, AMWG) in April 2010 (proposed venue - Saguaro Lake Ranch, Ariz.).
- Oral presentation (Wright and Korman) to TWG on progress of physical submodel upgrade (shifting sand rating curve model), along with simulations of suspended-sediment concentrations between Lees Ferry and Diamond Creek (output delivered to Walters for use in EwE model) during fall/winter 2009–10.
- Results of isotopic analyses of flannelmouth sucker otoliths from State University of New York laboratory.

FY2011

- Submission of refereed journal article with Josh Korman on "Surprise and opportunity in Grand Canyon ecosystem management"
- Contributions by Senior Ecologist and co-investigators to the high-flow experimental synthesis (proposed as report by Schmidt and others) relating to the sediment and biological responses associated with the 1996, 2004 and 2008 experimental releases.
- Multi-attribute tradeoff analysis (MATA) workshop deferred in FY2011

Budget

FY2010: $239,986
FY2011: $148,945

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Appendix A

Nearshore Ecology Proposal

Funding Opportunity Number: 09WRPA0001

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Date of Proposed Research: February 1, 2009 – September 20, 2012

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Section 1 Study motivation - The primary goal of this project is to understand how river flow, through its interaction with physical habitat structure, influences the survival rates of juvenile native and non-native fishes in the Colorado River in Grand Canyon. Nine research questions related to this goal have been identified in the RFP (RFP pages 27-28). These questions have a hierarchical structure and vary in scope. Some questions are fundamental and process oriented in nature (e.g., does river flow conditions alter juvenile native fish survival rates?) while others are focused on methodology (e.g., how to measure juvenile fish abundance, can small fish be marked?). Some questions, though related to the broader goals of the RFP, are quite specific (e.g., what is the Colorado River mainstem survival rate for humpback chub emigrating from the Little Colorado River (LCR) during freshets?). Some questions will be very difficult to answer within the time-frame of this project (e.g., how do biotic and abiotic factors influence individual fish growth and survival by habitat type?), or may be quite easy to answer with existing data (e.g., what is the feasibility of marking small humpback chub?).

We propose two key fundamental research questions (RQ) should guide the design of this project:

> ***(RQ1) Do steadier flows during summer and/or fall increase survival rates of juvenile native and non-native fish?***
>
> ***(RQ2) To what extent does physical habitat structure (e.g., sand bars and backwaters), in conjunction with flows during these periods, influence survival rate?***

We propose to address these research questions and link results to a proposed conceptual model for humpback chub *Gila cypha* (HBC) and other native and non-native fish (below) by first describing an approach to assess shifts in fish density by tracking habitat specific abundance and survival of native and non-native fish in response to changing near-shore habitat availability related to and created by the fall steady flow experiment. We then detail an approach to determine the source populations of juvenile native fish that populate near-shore habitats created by the proposed Fall Steady Experimental Flow (FSEF). Our intent is to link this new insight into juvenile fish ecology, with a focus on humpback chub, with the flow and habitat management capabilities of the Glen Canyon Dam (GCD) Adaptive Management Program (AMP), to create a better understanding of how flow and habitat management can be used to cultivate and enhance survival of juvenile native fish and, with time, adult native fish populations in Grand Canyon.

Section 1.1 Conceptual Model – The questions developed in the RFP (RFP pages 27-28) and RQ1 and RQ2 are part of a broader conceptual model of native and non-native fish population dynamics developed over the last 10-15 years in Grand Canyon. Such models have a long history of development in the Glen Canyon Dam Adaptive Management Program (e.g., Walters et al. 2000), and we summarize essential elements for juvenile humpback chub as they relate to this proposal:

A. *Humpback chub juveniles recruit to the mainstem juvenile population from the Little Colorado River as very small juveniles during the spring, and larger juveniles recruit to the mainstem during monsoon-driven flood events in late-summer and fall, or from mainstem spawning events.*
B. *The quantity and quality of juvenile habitat in the mainstem is driven by variation in flow and temperature regimes and also channel morphology. Habitat characteristics are determined by the monthly average discharge and hourly variation in discharge from Glen Canyon Dam, as well as sediment supply in the mainstem, and the frequency and timing of flows from Glen Canyon Dam designed to create habitat believed to be important for native fish (e.g., backwaters).*
C. *Survival rates of HBC juveniles in the mainstem depend on the quantity and quality of physical habitat, food availability, and the intensity of competition and predation from both native and non-native fishes.*
D. *Abundance of HBC juveniles will increase with improvements in the quality and quantity of habitat because survival rates will be higher. Over the long-term, greater juvenile production will increase the abundance of the adult population.*

Section 2 Experimental Design - To resolve uncertainties in the conceptual model above, survival rates, growth, and abundance of native and non-native juvenile fish must be quantified under contrasting conditions of flow, which, in turn, drives variation in habitat availability and quality. The experimental design for this project, which determines the extent and timing of contrasts, has already been defined, in large part, by the GCD AMP. Over the next five years, there will be hourly variation in flow rates (related to diel variations in energy demand) during summer months (Mean Low Fluctuating Flows, MLFF, June-August), and lower, steady experimental flows during the fall (Fall Steady Experimental Flows, FSEF, September and October). We will quantify abundance, survival, habitat use, growth, and natal source of selected native and non-native juvenile fish over three flow periods (summer MLFF, MLFF-FSEF transition, FSEF) based on four sampling trips (trip launch month July, August, September, October, Table 1) given this experimental flow regime. Due to costs, natal source would be determined for only a sub-set of species (likely HBC only) after discussions with partner agencies.

Section 2.1 Sampling methods to estimate fish habitat use, growth, and survival –
Estimation of juvenile abundance, survival rate, growth rate, and habitat use is fundamental to resolving uncertainties in the conceptual model and the two key research questions outlined and identified above. We propose sampling trips in late July and late August to characterize abundance, habitat use, growth, and survival rate of juvenile fish over the summer under MLFF flow fluctuations. These trips would be followed by sampling trips in early September and late October to characterize juvenile fish responses during the MLFF-FSEF transition, and FSEF period. Differences in abundance in each habitat type, between each sampling trips would be used to estimate habitat specific, reach-wide survival rates across flow events.

We propose two basic sampling approaches for estimating these characteristics: (1) reach-wide abundance estimation (RWAE); and (2) robust-design mark-recapture (RDMR) at replicate sites. The RWAE approach follows the two-stage design developed by Korman (2009) to track abundance, habitat use, growth and survival of age-0 rainbow trout in the Lee's Ferry reach of the Colorado River. Applying this approach to native and non-native juvenile fish in the lower Colorado River, we would:

(1) Select a relatively large study reach that contains multiple habitat types (e.g., Kwagunt rapid [River Mile 56] to Lava Chuar rapid [River Mile 65.5]) and stratify this reach into sites by habitat type (informed by, and integrated with, ongoing GCMRC project 2, Table 2);

(2) Sample fish at a large number of randomly selected sites within the reach using methods established in previous GCMRC efforts and Korman 2009 (e.g., single-pass electrofishing and mini-hoop nets) to quantify catch per effort. Site selection would be stratified by habitat type which, in turn, would likely require use of multiple gear types. Gear types and number of samples required will be informed by, and integrated with GCMRC ongoing projects 1, 3, 5, 6, 7, 11 and Trip 1 of this proposal, Table 2 ;

(3) Quantify capture probabilities by habitat/gear type, species, and fish size using short-term, closed, mark-recapture experiments (number of sampling events per trip $\geq$ 2 depending on recapture rate and number of sites from 2 above, e.g., Korman et al. 2009 [see Appendix]) at a smaller number of sites;

(4) Convert catch-rates at index sites (from 1 above) to population estimates based on capture probabilities estimated from (3 above); and

(5) Scale up site-specific estimates of population size to a reach-wide estimate based on the amount of habitat of each type in the reach.

Population size by sampling trip would be estimated for each habitat type and will be used to examine seasonal and flow-driven changes in habitat use. Fish would most likely be marked with a gear, habitat, and sampling pass specific mark using unique location and color combinations of Visual-Implant-Elastomer (VIE) (Brennan et al. 2005; GCMRC NSE pilot sampling, fall 2008). Ideally, unique marks would be applied to each animal (Bailey et al. 2004 for an example with VIE marks). Growth during summer-unsteady and fall-steady periods could be quantified based on differences in length-frequency distributions over time, as well as by measurements of otolith increments on a small sub-sample of fish (as in Korman and Campana 2009 [see Appendix]; see also section 2.2.3 and 2.2.4 of this proposal). As in Korman (2009), we would integrate most information from the proposed program in a stock synthesis model to jointly estimate parameters of interest (including abundance and survival rate by habitat type, growth, recruitment to the juvenile population over the growing season) and to identify shifts in habitat use. This approach is based on standard closed population mark-recapture approaches to estimate abundance and capture probability (analogous to those outlined in Otis et al. (1978)) and allows for incorporation of size dependence in capture probability (to account for heterogeneity in capture probability by size). The critical assumption of the RWAE approach (and all closed population models) is that the population can be treated as effectively closed within trips and that differences in abundance across trips are caused by recruitment (LCR and mainstem) and mortality only. The approach is unable to separate emigration from mortality. Radio telemetry data, and movement rates of marked fish within sites across trips would help evaluate the extent of potential emigration from study sites (see section 2.3.2 of methods). Immigration would be estimated. Differences in abundance and distribution among habitat types across trips would be used to estimate survival and changes in habitat use during changing flow conditions from summer MLFF, the MLFF-FSEF transition period, and FSEF conditions. If significant changes in abundance are observed, an additional sampling trip, if supplemental funds were available, following the return to normal flow operations in November could be added to assess fish population responses to the transition from experimental steady flows to winter operation flows. Modal shifts in length-frequency and direct ageing would be used to evaluate growth.

The second approach to estimating growth, survival, and abundance by habitat type is based on a robust design mark-recapture approach (RDMR) that would estimate habitat specific abundance for each trip using closed models (RWAE), and relax the assumption of population closure between sampling trips (Pollock et al. 1982). Essentially, the RDMR provides a finer-scale assessment of abundance and survival, and is generally similar to RWAE with the following differences:

(1) Select a series of study sites within a broader reach (e.g., three to four 500-m sites between Kwagunt and Lava Chuar rapids). These sites would likely each contain a mix of all or most of the habitat types within the broader reach.

(2) Conduct multi-pass (3-5 pass events) mark-recapture assays in each of the study sites during each of the four trips.

(3) Estimate abundance at each study site on each trip.

As with the RWAE approach, we would employ a marking strategy to estimate abundance within habitat types at each site for each trip. Multiple gear types would likely be needed to sample the full range of habitat types and water depths. Under the RDMR approach, we would assume that populations within each site are effectively closed within trips, but not among trips. We would also assume that changes in abundance at the sites across trips represent changes at a reach-wide scale. Differences in abundance and distribution in each habitat type across trips will be assessed during summer-MLFF, MLFF-FSEF flow transition, and FSEF periods. Survival estimates for each habitat between sampling trips could be estimated using open population models (Pollock et al. 1990) following the robust design framework. If the recaptures between trips are too low to estimate survival, then the RDMR approach basically collapses to the RWAE approach for estimating survival – i.e., these approaches are not mutually exclusive in design or analyses employed. Shifts in length-frequency and direct ageing using otoliths will be used to evaluate growth (see section 2.2.3).

Section 2.2 Site Selection - We propose to use existing data and models from the GCMRC physical science program (Projects 1, 2, and 10, Table 2 to quantify habitat availability over the study reach that contains the RDMR sites, habitat availability within the sites, and how habitat changes with flow. Such an approach has already been used to quantify juvenile chub habitat use in the Colorado River near the LCR (Korman et al. 2003). The existing GCMRC shoreline GIS database and other surveys can be used to stratify habitat into classes such as talus slopes, open sand bars, vegetated sand bars, cobble bars, and backwaters. Existing bathymetry and hydrodynamic two-dimensional models that cover the entire study reach can be used to predict water temperature, depth and velocity in shoreline habitats at daily minimum and maximum flows during the summer-unsteady period, and at the average flow during the steady-fall period (Korman 2003; Projects 1 and 10, Table 2). Velocity and temperature criteria will be used to further classify habitat for various species and life stages (e.g., into usable and unusable categories, or some finer scale). Additionally, shoreline stability during the summer can be quantified based on daily flow variation. For example, in summer, backwaters that are barely flooded at the daily maximum flow may be far more stable, warmer environments than those subject to complete inundation on each diel flow cycle. Similarly, steeper shorelines with cover (e.g., vegetated cut banks) may be more stable than low angle, open sand bars or cobble bars, where low velocity littoral areas vary more. These characteristics of stability can be related to patterns of fish habitat use (density or occupancy) to help evaluate effects of fluctuating flows. A strong relationship between fluctuating flows, near-shore habitat use, and otolith growth has been observed for age-0 rainbow trout in the Lee's Ferry reach of the Colorado River (Korman and Campana, 2009). Similar relationships are expected for juvenile native and nonnative fish in the Grand Canyon and, in fact, is part of the motivation for the current fall steady flow test. We hypothesize that unstable habitat types will be used only minimally during the summer-unsteady flow period, but that use of these habitats will increase during the fall-steady period when flows are stabilized. If this difference in habitat use is ecologically important, we would also predict increase in growth and survival during the fall-steady flow period relative to the summer. Information we collect as part of Sections 2.1 and 2.3 can be used to test these ideas directly.

Section 2.3 Assumption evaluation and alternative approaches to assess native fish habitat use and response to FSEF - Any mark-recapture approach to estimating abundance and density depends on recapturing sufficient numbers of marked individuals to draw inferences on the parameters of interest. In many fisheries mark-recapture studies, capture probabilities are low (often < 10%, Pine et al. 2003) and heterogeneity in capture probability across fish size is often observed (Pine et al. 2003; Korman et al. 2009; Coggins 2008). Closed population models generally have fewer parameters (and assumptions) than open models and are thus better able to estimate parameters of interest (capture probability and abundance) when recaptures are low. By design, some closed models can account for heterogeneity in capture probability directly (i.e., M_h type models, Otis et al. 1978) or captures and recaptures can be stratified by length group and capture probability estimated for each length stratum. These are two key reasons why closed population models have been recommended for use in fisheries studies to estimate abundance (Pine et al. 2003). One concern is the closed model assumption of no emigration from the sites of interest (i.e., habitat specific sites) both for the RDMR and RWAE approaches to estimate site specific abundance. Korman et al. 2009 successfully used closed model techniques in the Lee's Ferry reach of the Colorado River to estimate capture probabilities of juvenile rainbow trout across spatially discrete sites. These authors evaluated closure assumptions by employing a site specific marking technique and then sampling up and down-stream of their study reach to estimate emigration from each site. Emigration rates were low, ranging from 2.2-2.6%, leading these investigators to conclude that rainbow trout populations within discrete sites effectively can be considered closed. We would evaluate the closure assumption in our mark-recapture experiments using methods similar to Korman et al. 2009. Additionally, recaptures of fish marked on previous trips will provide useful information on growth and movement (e.g., movement into backwaters during periods of steady flow) between sampling trips and associated flow conditions. The NSE pilot sampling data from 2008 should provide some information on closure and also provide information on capture probability which is necessary to fully assess how violation of the closure assumption biases abundance estimates. Zehfuss et al. (1999) demonstrate declining bias in abundance estimates with increasing capture probability and emigration from the study site for Jolly-Seber and robust design models.

Section 2.3.1 Estimating site occupancy - If catches and recapture rates within trips are low, abundance estimates within sites will be highly uncertain. However, as pointed out in the RFP, in this case it will be possible to retreat from estimating abundance to estimating the probability of site occupancy (by habitat type and over time; MacKenzie et al. 2006). Site occupancy, although not as useful as direct estimates of abundance, can be used to index habitat use and changes in habitat use over time and with associated changes in flow. In all likelihood, the mark-recapture program will be able to estimate habitat-specific abundances for some species and size classes, and occupancy would be estimated for species and sizes with lower abundance and/or capture probability. Total number of site visits required would be based on trip 1 and information from ongoing GCMRC projects 3, 6, 7, 11 (Table 2).

Section 2.3.2 Incorporating telemetry information - The potential exists for radical changes in capture probability or behavioral shifts by fishes across sampling events within a season (~July-October) due to fish growth and possible ontogenetic habitat shifts such as fish moving into deeper, less accessible portions of the river. These behavioral shifts could also be caused by the designed flow experiments and associated changes in available habitat, or biotic interactions (changes in food availability or predation risk). To examine these behavioral responses, directly assess habitat use, and test capture-recapture model assumptions such as closure, a small sub-set of native and non-native fish (5-10 individuals of 3-4 key species, including humpback chubs, > 150-mm TL) will be tagged with telemetry tags and their movements, habitat use, and fates assessed directly.

Implantable, compact telemetry tags coupled with autonomous receivers (which monitor a given area continuously for extended time periods for the presence of tagged animals) and deployed as a fine scale array within a sample reach could allow the telemetered animals to be "virtually" captured by detecting their tags as they move through the environment via either the autonomous receiver array, or from boat-based receiver units when field crews were onsite. This technology is mature, and thousands of telemetered fish and autonomous receivers are currently deployed globally (Simpfendorfer et al. 2008; Hedger et al. 2008). However, the use of telemetry techniques in Grand Canyon is technologically challenging, given the large amount of ambient noise from rapids, moving rocks, and coarse sediments, all of which greatly impair the ability to detect acoustic tags. Radio tags have been used successfully in Grand Canyon to track movements of adult humpback chubs (Valdez and Hoffnagle 1999) in response to flood events, but the attenuation distance of radio tags is greatly impaired by high conductivity in areas of Grand Canyon near the Little Colorado River. Current GCMRC projects 3 and 7 have been involved in several pilot projects exploring the utility of these techniques with non-native fishes to assess movement and capture probability. Industry cooperator Marlin Gregor, President of Sonotronics Inc. (http://sonotronics.com) has been involved in the above projects and has developed specific tag and receiver design combinations to maximize the potential of this technology in the challenging conditions presented by the Colorado River in Grand Canyon. Marlin Gregor has also agreed to accompany on our first sampling trip as we test a variety of receiver and tag types. If this pilot sampling during trip 1 reveals poor performance of telemetry equipment due to high levels of ambient noise in Grand Canyon, we will abandon the telemetry component of this project. We will work with cooperators to then identify alternative research efforts such as experiments to assess DNR:RNA ratios as a measure of short-term growth as recommended by NSE review panel.

The incorporation of telemetry information with the mark-recapture sampling is experimentally risky, but has huge potential to boost our ability to draw inferences about juvenile fish abundance and habitat use. Pollock et al. (2004) showed an example of using both tag types to improve estimation of fishing and natural mortality rates using a complementary, multinomial approach to the tagging component of the stock synthesis model used in Korman et al. in-press and this proposal. We have extensive previous experience with these types of telemetry systems and similar applications (Bennett 2005; Marcinkiewicz 2007; Tetzlaff 2008; Burgess 2008). Coupled with ongoing GCMRC projects 3 and 7, and industry cooperator commitment, it is likely that technological hurdles could be overcome. Exact tag types, receiver deployment strategies, numbers of tags and receivers required would be determined based on in-situ range testing of tag and receiver combinations. An array network would not guarantee perfect, continuous detection because behaviors of individual animals such as occupying habitat types similar to interstitial spaces between rocks, would attenuate the signal from the sonic tags. Conceptually, an autonomous receiver array could be deployed during a July sampling trip (first trip of sampling season) and a small batch of fish tagged and released with telemetry tags. The receivers would then remain deployed, monitoring these fish until the next sampling trip, at which time the data would be retrieved and an additional batch of fish tagged. Similar procedures would be followed for each additional trip, until the last trip of the year when no additional fish would be tagged and the receivers would be removed from the study site. Multiple batches of fish would be used (a "staggered entry" design, Pollock et al. 1989) because of limitations in tag battery life. The staggered entry design would allow specific size cohorts of fish to be tracked from the first through the fourth study period coincident with the same flow transition periods discussed in Section 2.0.

Section 2.3.3 Determining origin of recruits – The FSFE will likely almost immediately create thermally favorable microhabitats for juvenile HBC and other native fish (RFP, page 27) which motivates Question 6 of the RFP (page 27), "*Are replicated flows September-October steady flows (2008 through 2012) likely to improve the survival and recruitment of young humpback chub in the Colorado River ecosystem?*" Additionally, while management actions such as FSFE are certainly likely to modify and create habitat types, some of which may be favorable to juvenile HBC, where do the juvenile HBC come from to colonize these habitats and if they colonize these habitats, how well do they survive? As outlined in Sections 2-2.2, we describe approaches to assess survival of young HBC (and other species) in response to the FSFE. However, recruitment of young HBC and other juvenile fish from the LCR to the mainstem study site during July-September (Conceptual Model point A) could confound information on patterns in juvenile fish density in different habitats and their survival, unrelated to flow events. For example, in the absence of any direct measure of age-0 fish recruitment from the LCR to the mainstem population, observed patterns in density, growth, and survival of juvenile fish from our mark-recapture study could be attributed to the flow experiment, when, in fact, these density changes were actually independent of the experiment, and instead related to natural emigration from the LCR to the mainstem. Without an understanding of this recruitment from the LCR to the mainstem, the estimated growth, survival, and movement among habitat types in the mainstem from the tagging data (Sections 2-2.2) could be confounded with new recruits.

We propose to use otolith microchemistry to determine the origin of juvenile fish (mainstem vs. LCR), most likely only HBC because of cost concerns, utilizing available habitats across the different flow regimes from July-October. As pointed out in the RFP (page 27) there are at least two potential sources of juvenile HBC that use habitats available during MLFF and migrate to habitats created by FSFE: (1) LCR spawned juveniles that enter the mainstem river in May-June outmigration and (2) LCR spawned juveniles that remain in the LCR until they enter the mainstem following July-September freshets. A third possible source of HBC juveniles would be mainstem spawned individuals who could also be identified through otolith microchemistry. This information will be used to compliment and strengthen inference from estimates of habitat specific patterns in abundance, movement patterns of telemetered fish, and fish size distributions (Sections 2.1-2.3).

Otoliths are paired structures that form part of the inner ear of teleost fish and are commonly used by fisheries researchers to estimate fish age, and increasingly, their chemical constituents are used to determine fish movements (Campana 2005). Otoliths are composed of biogenic calcium carbonate that accretes new crystalline and protein material daily. Within these accumulating layers, trace elements are incorporated into the otolith from the fishes environment, creating a temporal sequence of accumulated elements. This represents a chronology of the environment the fish has occupied over its life (Elsdon et al. 2008). Within the otolith, the different accumulated elements and chemical signatures can be used as a natural tag. These tags can then be linked to groups of fish that have similar chemical signatures to show associations of fish with their environment in both time and space (reviewed in Elsdon et al. 2008). Chemical signatures in an otolith can be examined, for example across a transect, to assess patterns in chemical profiles at different ages of the fish. When these chemical signatures are paired with information on the chemical profiles of the water in the spatial locations where the fish could have lived, movement patterns of individuals and groups of fish can be determined. A key assumption is that the chemical signatures from the different environments are separable, and that these signatures can be matched on the correct temporal scale. To test these assumptions, during 2009 we will test our proposed methods on flannelmouth sucker (*Catostomus latipinnis*) a more common native species thought to have similar life history characteristics as humpback chub. Samples of flannel mouth sucker are also available from the 2008 NSE pilot sampling (M. Yard, USGS-GCMRC, personal communication). We will attempt to analyze at least a sample of these otoliths from 2008 to inform 2009 field collection efforts. Additionally, we will also examine a sample of previously collected adult humpback chubs used in earlier analyses (Hendrickson 1997).

Recent advances in otolith microchemistry will enable us to assay for a suite of major, minor, and trace elements through the use of laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS; Figure 1). SUNY-ESF has just acquired a state-of-the-art laser ablation system (New Wave Research UP-193 nm solid state) and has connected it to an also new Perkin-Elmer DRC-e ICPMS. This setup, with analytical resolution to low ppb and spatial resolution to approx. 10 microns, will be used to collect the bulk elemental data, using one of each pair of lapillar otoliths. Other data, potentially including strontium and other stable isotopic ratios will be taken on the corresponding otolith at a partner institution such as University of Arizona Lunar and Planetary Science Laboratory or the Department of Nuclear Physics at Lund University in Sweden (where KL has ongoing collaborations since 1997). In addition, we will explore the utility of trace elemental mapping by means of synchrotron-based X-ray fluorescence (S-XRF) at the Cornell High Energy Synchrotron Source (CHESS). The S-XRF will allow us to explore which elements might be of interest to trace using the LA-ICPMS. This approach of using the S-XRF to first map multiple trace elements in otoliths and the coupling of this information with high-resolution LA-ICPMS work has provided new insights into the environmental history of a variety of fish (marine and freshwater) and their lifetime movement patterns (see Limburg et al. 2007). Given that run times per otolith are long with S-XRF, and time available is limited at the CHESS facility, we anticipate that bulk of the work will be accomplished using LA-ICPMS once multiple otoliths have been mapped at CHESS. In addition to addressing questions related to the near-shore ecology of Grand Canyon fishes proposed here, there are obviously additional research questions that these approaches could be applied to using otoliths from existing collections. For example, older fish from archival collections (HBC otoliths used in Hendrickson 1997) are prime candidates for S-XRF mapping coupled with LA-ICPMS analysis to assess movement patterns and provide alternative age assessments of larger, older, fish collected at earlier time periods during different river conditions. If suitable archived samples were available, such as from HBC spawned prior to the Glen Canyon Dam, it would be very interesting to assess the life time movement patterns (spawning, rearing, and migratory) or pre- vs. post-dam HBC or other native fish.

As an example of this approach Limburg (1995, 1998, 2001) used ratios of strontium (Sr) relative to calcium (Ca) from American shad (*Alosa sapidissima)* otoliths along a transect in the Hudson River, linked with otolith derived age estimates to identify the age and size when American shad were transitioning from the Hudson River to the Atlantic ocean. Limburg (2001) compared Sr:Ca ratios and size and age structure in young-of-year American shad with the Sr:Ca ratios of adult fish from these same cohorts migrating back to spawn in the Hudson River in subsequent years. From these comparisons Limburg (2001) found that in three of the four year classes analyzed, differential mortality had occurred in juveniles, and was related to time of emigration from the Hudson River. A similar approach with humpback chubs over multiple years, coupled with Sections 2-2.2 of this proposal, could help us to identify the linkages between the timing of out migrating juveniles from the LCR, available rearing habitat in the mainstem as determined by flow conditions, and the interaction between available habitat and juvenile fish survival.

Section 2.3.4 Determining growth and survival using otoliths - Measurements of fish growth integrates information from a variety of environmental (e.g., temperature) and biotic (e.g., food availability) sources into a useful single metric. Growth can be used, for example, as a response metric to a variety of management options (DeVries and Frie 1996) and also used to provide insight into survival patterns (Lorenzen 1996). For larval and juvenile fish, growth information is commonly measured by analyzing size frequency distributions or using fish hard parts such as otoliths (DeVries and Frie 1996). The use of otoliths to determine juvenile fish growth has been used to address a variety of questions for Colorado River native (Bestgen et al. 2006) and nonnative fish (Korman and Campana 2009). For example, Korman and Campana (2009) documented a strong relationship between fluctuating flows, near-shore habitat use, and rainbow trout otolith growth rates in the Lee's Ferry reach of the Colorado River. As proposed in section 2.2, we hypothesize that fish growth may change as a function of shifts in habitat utilization driven by flow related changes in habitat availability – thus differences in growth may be evident between MLFF, MLFF-FESF transition, and FESF period.

We propose to assess growth in three ways: (1) by tracking modal progression of native and non-native fish size in during each sampling trip, (2) if unique VIE marks are possible through recaptures of marked fish, and (3) direct estimation using otoliths collected for the microchemistry analyses of HBC described above. The first approach is straight forward and simply requires plotting the size frequency of individuals from each species and sample trip as a function of length and identifying distinct peaks in the distribution. These peaks are then followed in subsequent trips and growth estimated by tracking the progression in the modal peaks of each size frequency distribution.

This approach generally works best if sample sizes for each cohort are large and growth is fairly uniform among cohorts such that the size modes for each cohort can be distinguished. If sample sizes are small or growth within a cohort is inconsistent, then cohort modes become indistinguishable in the length frequency distribution and estimating growth is not possible. This approach is low cost, non-lethal, and would be used to estimate growth for all possible fish species.

The second approach is dependent on being able to mark fish for the capture-recapture experiment using unique marks. The VIE marks we propose to use come are available in a variety of colors and there are numerous body locations in which fish can potentially be marked. However, it is not until live fish are examined and the color patterns and marking locations assessed to determine whether VIE colors can contrast sufficiently with natural fish color patterns to offer reliable marking locations. We acknowledge the difficulty in creating a unique marking scheme and the potential bias induced in the analyses from mistakes made in the marking program thus necessitating careful consideration to the design of the fish marking program.

The third approach is based on the standard technique of visually counting daily growth rings on otoliths to estimate age (Pannella 1971; Stevenson and Campana 1992; Pine and Allen 2001). Following this approach, the second HBC otolith from whichever otolith pair is used for the microchemistry analyses (most likely the lapillar pair; Hendrickson 1997) would be mounted individually on microscope slide, polished to the mid-plane following standard otolith preparation procedures, examined at 400-1250x using a compound microscope, and then the daily increment marks on the otoliths from the origin to the edge counted 2-4 times. Daily otolith increments have not been validated in humpback chubs, but preliminary work by Hendrickson (1997) provides strong circumstantial evidence to suggest that the lapillar increments do form with daily periodicity. If recapture rates between trips are sufficiently high as evident from trips 1 and 2 in field season 1, a validation study could be designed by immersing juvenile HBC in an alizarin solution to “mark” the otolith, then releasing the fish with the expectation to recapture that fish on a future trip. Recaptured fish would then be sacrificed, otoliths removed and prepared as described in section 2.3.4, and the otolith rings since the immersion in alizarin counted and compared to the actual days elapsed (Devries and Frie 1996). Average daily growth rates can then be determined from dividing the fish TL when captured by the age.

Recent juvenile HBC growth over short time periods, such as just prior to and during the transition from MLFF to FSFE and during the FSFE, could be estimated by measuring otolith growth increments from the nucleus to a distance along the growth axis that would correspond to a point in time (and the fish’s life) during MLFF, and then measure from this point to a second point that would represent the time period including the MLFF-FSEF transition, and then a third measurement from the MLFF period to a time period near the end of the FSEF. The approach outlined would obviously be dependent on collecting juvenile HBC near the end of the FSEF such that the growth transition could be measured across each of the three flow periods described. Obviously these candidate fish would have to survive any changes created by the flow events – and it would be impossible to collect growth information on any fish that died during the flow events. Alternatively, juvenile HBC could be sampled on each of the four sampling events and incremental growth measured from these fish using methods described above. However, given the short time period between the flow treatment and the timing of the sampling trip, contrasting growth information may be not detectable along the post-rostral edge of the otolith because not enough time may have elapsed for sufficient otolith deposition along the edge to see or measure. This growth information would be linked to the otolith microchemistry results related to natal origin of HBC. For example, this linkage could be useful in assessing growth patterns of HBC that were early vs. late season emigrants from the LCR to mainstem Colorado River or growth patterns of mainstem origin juvenile fish.

A major drawback of using otoliths to estimate age and growth is that the fish must be sacrificed to extract the otoliths. Given the listing status of most native fish in Grand Canyon, including HBC, we share concerns that any research associated mortality could be deleterious to the population overall, and we acknowledge that permits to collect and sacrifice these fish may be difficult to receive. Recruitment trends for humpback chubs and other native fish have been increasing over the last 4-5 years (ongoing GCMRC projects 5, 6, Table 2; Coggins 2008) reducing the potential for population impact from removing a small number of native fish from the population for research needs. Exact numbers of fish required would be determined by examining otoliths from juvenile humpback chubs incidentally taken as part of routine sampling in prior research efforts (i.e., Near-shore Ecology pilot sampling in August and September 2008 and backwater sampling efforts in summer 2005). We propose to collect a small number of juvenile fish, most likely 5-10 age-0, age-1, age-2, and age-3 humpback chubs and also flannel mouth suckers each trip (no more than 50 fish per age class and species per year). In addition to providing information from the microchemistry and age-growth analyses in response to the FSEF, there are at least two other major areas that could be assessed by using tissues from these animals. First, age information on these small fish would be very useful in informing the age-length key used to assign age-at-first capture in the standard age-structured mark-recapture program (ASMR, Coggins et al. 2006a; GCMRC projects 4 and 6, Table 2) used to assess trends in HBC growth, recruitment, and survival (Coggins et al. 2006b; Coggins 2008). This age-length key is currently based on a limited set of approximately 60 estimates of HBC length-age (Coggins 2008) and this small growth sample, particularly for very small and young fish, could be improved with additional growth information possibly leading to reduced bias in the recruitment estimates from the ASMR model. Additionally, the previous growth data were not collected during the recent time period of warmer water temperatures, which may have led to increased HBC growth. Thus, the currently used growth information may be negatively biased due to slow growth of humpback chubs in cold-water conditions vs. the current warmer-water conditions.

Fin rays also offer an alternative approach for aging fish to otoliths with the major advantage of not having to sacrifice the fish (DeVries and Frie 1996). Using a sub-set of fish sacrificed for otolith analyses, we will conduct an exploratory analysis to assess the feasibility of the same age and microchemistry assessment on the fin ray sections as on the otoliths. This will provide information on the possibly utility of using fin rays as a non-lethal technique to determine age of young fish to help inform the HBC stock assessment and monitoring program (ongoing GCMRC projects 3 and 4). If successful, and necessary, this approach could provide information useful to assessing recruitment responses of HBC to planned and unplanned experiments at younger ages (and less time lag) than the current 3-4 year response time required before fish recruit to the tagging program and recruitment trends assessed as part of ASMR.

A final alternative for both the microchemistry and otolith based age and growth estimation would be to use a surrogate species for humpback chubs that was thought to have a similar life history. Alternative species to humpback chubs could include native fish such as bluehead suckers *Catostomus discobolus*, flannelmouth *Catostomus latipinnis* suckers, speckled dace *Rhinichthys osculus* or nonnative species such as fathead minnows *Pimephales promelas*.

Section 3.1 Contingency plans to alternate flow scenarios, expanded spatial replication, or inability to secure variance during no-motor season – The proposed sampling framework and experimental design (i.e., timing of trips) can easily be modified to address alternate flow-related hypotheses. For example, question (9) in the RFP (page 28), "*What happens to juveniles that used the warmed areas when fluctuating flows are resumed?*", could be addressed by adding one or two trips (and additional costs) to the proposed four-trip schedule. In this case, a trip following the resumption of fluctuating flows, (mid-November) and an additional trip one month later, would quantify immediate changes in habitat use as well as survival rates under fluctuating flows during early winter. A similar strategy, where sampling is conducted before and after a beach habitat building flow, could be used to evaluate the effects of flows above power plant capacity or normal daily maxima (item 6, RFP page 31). Additional spatial sampling, at other known HBC aggregation sites ("Randy's Rock", RM 126; "30-mile", RM 29-32) could also be implemented based on results from Section 2 above. The key point is that our approach will provide estimates of habitat use, survival, growth, and origin of juvenile fish during summer and fall, and that it is relatively easy to expand sampling into other times of year to look at other flow-related hypotheses. That said, the objectives and research questions that are the focus of the RFP are very challenging. Our philosophy is to do a few things well, rather than many things poorly. Given available resources, we will focus on population dynamics during summer and fall only as outlined above.

We expect that some elements of the proposed sampling framework would become part of the GCD AMP's long-term monitoring protocol. For example, methods developed in this project could be used to estimate juvenile HBC abundance in the mainstem during late summer and late fall. Over many years, these estimates could be related to recruitment estimated from the Age-Structure Mark-Recapture (ASMR) model (Coggins et al. 2006 a, b). Ultimately, a stock-recruitment relationship between age-0 chub in the mainstem during both fall and summer, and recruitment determined from the ASMR model, would be very helpful in the interpretation of the juvenile data. For example, if there is strong density dependence in survival between summer and fall, and little density dependence for later life stages, we would expect an asymptotic relationship (e.g., Beverton-Holt shaped relationship) between summer and fall juvenile abundance, and between summer juvenile abundance and ASMR-based recruitment estimates. In this case, there would also be a strong linear relationship between fall juvenile abundance and ASMR recruitment. Such analyses are very relevant to current policy debates. For example, strong density dependence between summer and fall would indicate that it is unlikely that improving habitat conditions during the summer will result in substantive changes in juvenile abundance during the fall, and consequently to improvements in recruitment to the adult population. It will take many years to establish reliable relationships (which will likely be noisy), but we see no alternative for the GCD AMP. Ultimately, life-stage specific stock-recruitment functions need to be established to fully interpret results from the proposed study in the context of GCD AMP management objective for adult HBC.

Depending on the start of the FSFE, it is likely that one or two of our proposed sampling trips would launch after the start of the no-motor season (September 15). In this case, we would require a variance from the Park Service for operating motorized equipment (boat motors and generators) required for our electrofishing sampling. While we intend to use multiple gear types (most likely electrofishing and hoopnets) during each of our sampling events, we have high expectations for successful electrofishing sampling for use in mark-recapture (Section 2.1) based on results from Korman et al. (2009) and fall 2008 Near-shore Ecology pilot sampling. Failure to secure a variance allowing us to use electrofishing would increase our dependence on hoopnet sampling to track patterns in habitat specific abundances, estimate survival, and track growth via changes in length frequency. Gear selectivity patterns between electrofishing and hoopnets likely differ, and by deploying both gears on each sampling trip we intend to minimize the confounding that can occur in the data due to changes in gear between trips and associated selectivity patterns (i.e., responses could be due to the flow experiment or simply to changes in the gear type). Compromises to help meet the Park Service's no-motor requirements are possible. One option would be to create a stash of 1-2 electrofishing boats in the study reach just prior to the end of no-motor season. Any trips that occurred during the no-motor season would then be supported by rowing trips out to the sampling sites, where electrofishing boats would be used to complete the required sampling effort. At the end of sampling, these boats would be floated or flown out of Grand Canyon in cooperation with other sampling efforts with USFWS and AZGF. Additional options would be to increase the reliance on telemetered fish and to follow the movements and habitat use of telemetered fish using rafts and kayaks during no motor season. A final option would be to not grant the variance; thus, electrofishing would not be possible. Our proposed closed population models (both mark-recapture and occupancy) estimates capture probability with each sampling trip, so if hoopnets were the only sampling gear available during the last trip, then our capture probabilities would be based on marks and recaptures from hoopnet gear only. Hoopnet catches alone would likely result in very low capture probabilities, limiting the use of some mark-recapture models. However, habitat occupancy using methods outlined in section 2.3.1 may be used to estimate occupancy even with low capture probabilities. If no variance is granted, extensive comparisons between electrofishing and hoopnet catches based on pilot sampling during motor season and previous fish sampling efforts in Grand Canyon would be done to develop a better understanding of the selective properties of each gear. The style of electrofishing developed and used by Korman et al. (2009) was first used in the Lee's Ferry reach, but was also used as part of the pilot NSE sampling during fall 2008 thus limiting the number of comparisons that can be made between gear types using historical data.

Section 4 Conclusions - Certain aspects of the proposed experimental design are beyond our control, and will limit the inferences from the resulting data. We propose to compare juvenile habitat use, survival, and growth during summer-unsteady and fall-steady flow periods to evaluate the potential benefits of steady flows. However, such an assessment assumes there is no seasonality in the parameters of interest, which we know is not likely to be the case. For example, growth rates will likely decline as fish increase in size, and as water temperature declines due to reduced solar irradiance. Habitat use may also have a flow-independent component that depends on fish size. Ultimately, the proposed work, or key elements of the proposed work, will need to be repeated under an alternate flow regime. The two logical alternatives are to extend the period of steady flows (e.g. July-Oct), or to revert to unsteady flows (MLFFA or greater fluctuations) during the fall. Results from the proposed work will be helpful in choosing among these alternatives because: (a) we will have a much better sense of our ability to detect changes in juvenile survival rates and other life history characteristics; and (b) expected and serendipitous insights from the proposed work will provide for more refined hypotheses and a more fully articulated conceptual model.

Section 5 Budget narrative - The proposed project budget (~$300,000 per year, for four years) is provided in the attached spreadsheet. The travel budget category (Part A) includes travel for University of Florida supported personnel to assist with field trips, meet with cooperators (including members of the GC AMP as specified in the RFP) including airfare, car rental, per diem, and lodging charges for trips to Flagstaff. Mileage charges are for local mileage in Gainesville for acquiring supplies and other project related activities on University of Florida vehicles. This category also includes a Flagstaff based lodging and utility expenses for field crews (a rental house or apartment) and other project personnel fur use during the field season, and also for approximately one month prior and after the field sampling events. Our intent is for several project staff to spend several months of the year working with GCMRC cooperators on this project to maximize interaction amongst cooperators and facilitate project planning, logistics, and analyses. The supplies category (Part B) includes items such as telemetry tags and receivers, surgery supplies for telemetry gear, and disposable field items such as batteries, vials, preservative etc. Charges for preparing the otolith samples for microchemical analyses are also included in this section. We have also included an Osprey boat for use during this project, but to meet budget requirements have spread these charges over several years. While GCMRC has two Ospreys available, these boats are in high demand by cooperating projects and we do not want field activities to be limited by a limitation of a specialized boat. The supplies section also includes charges from Ecometric consulting for development of specialized analytical software. Humphrey summit logistics is also included in the supply category to provide assistance with field activities related to the telemetry efforts including modifying Osprey boat for deploying and retrieving hydrophones and towable hydrophones for tracking. Part C is the wages, benefits and tuition section that covers University of Florida of Florida project personnel. This includes recruiting a PhD student to assist with all aspects of design, field sampling, and data analyses. This student will be paid a stipend, health insurance will be provided, and tuition to the University of Florida will also be paid by project funds. A portion of a technician/biological scientist employed by the University of Florida is also included on this grant as well as benefits for this person. Section D of the project is a subcontract to SUNY-ESF and includes tuition, stipend, and salary charges for a PhD student at SUNY-ESF. This student will assist with all aspects of the design, field sampling, and data analyses with particular emphasis on the otolith microchemistry work. Section D also includes a small travel budget for SUNY-ESF travel costs to meet with other project cooperators at GCMRC in Flagstaff. Costs associated with the LAICPMS analyses are also included in Section D. Section E includes indirect cost figures for the total award, for the sub-contract to SUNY-ESF and also transfer between USGS GCMRC and USGS CRU program. These indirect costs represent ~20% of the total costs of the contract. It should be noted that this contract includes support for two graduate students who could potentially be recruited by USGS GCMRC as fulltime employees to continue this type of work.

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Table 1. Proposed sampling schedule and key tasks for Near-shore Ecology of Grand Canyon Fish project. MLFF = Mean Low Fluctuating Flows, FSEF = Fall Steady Experimental Flows.

Year	Activity	Month	Trip Number	Likely river flow	Key tasks or project milestones
2009-2011	Field sampling	Late July	1	MLFF	Mark-recapture, deploy receiver array, implant telemetry tags, manual tracking of telemetered fish, collect fish for otolith analyses
2009-2011	Field sampling	Late August	2	MLFF	Mark-recapture, implant telemetry tags, manual tracking of telemetered fish, collect fish for otolith analyses
2009-2011	Field sampling	Early September	3	MLFF-FSEF	Mark-recapture, implant telemetry tags, manual tracking of telemetered fish, collect fish for otolith analyses, possible otolith validation experiment
2009-2011	Field sampling	Late October	4	FSEF	Mark-recapture, retrieve receiver array, implant telemetry tags, manual tracking of telemetered fish, collect fish for otolith analyses, possible otolith validation experiment
2009-2011	Sample processing	October - March			Estimate growth from size distributions, estimate abundance and survival from mark recapture, assess movement and habitat use from telemetry information, and conduct otolith analyses
2009-2011	Annual Report	April			Present annual project updates, submit reports, meet with all cooperators to revise sampling plans for upcoming field season
2011-2012	Analyze data and write report	May 2011-Aug 2012			2012 will include additional isotopic analyses of otoliths and funds for mapping chemical signature of water
2012	Final Report	September			Submit final report and presentation to GCMRC staff

Table 2. Existing monitoring and research studies in Grand Canyon as listed in the RFP. Numbers in this table correspond to referenced cooperative and complimentary research described in this proposal.

Project Number	Project title
1	Monitoring of biological and physical aspects of backwater habitats
2	Integrated analyses and modeling: mapping shoreline habitat changes
3	Monitoring mainstem fishes
4	Stock assessment of native fish in Grand Canyon
5	Investigate factors affecting the survival rate of juvenile native fishes in the mainstem Colorado River
6	Native fishes habitat data analysis
7	Nonnative control planning and pilot testing
8	Status and trends of Lees Ferry trout
9	Monitoring rainbow trout redds and larvae
10	Thermal modeling of near-shore habitat
11	Aquatic food base program

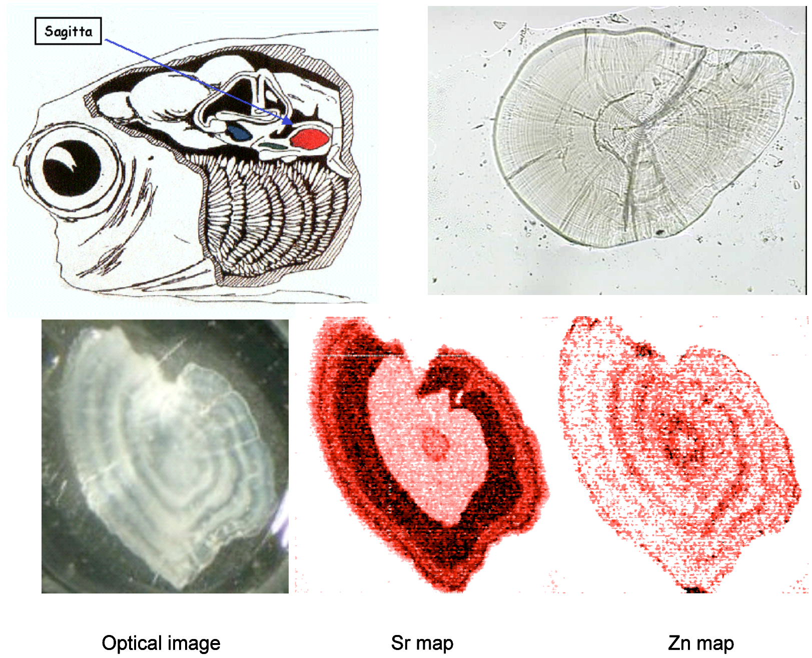

Fig. 1. Fish otoliths are located in the semi-circular canals underneath the brain (top left); daily growth increments seen in 0.5 mm otolith of young fish (top right); annual rings (bottom left) can be used to age adult fish, and elements such as strontium are deposited in proportion to ambient concentrations (bottom, middle) whereas zinc (bottom right), in this case, is deposited in a seasonal pattern. The analyses shown in the bottom two panels were conducted with a nuclear microprobe. This kind of analysis will continue to complement the work we are proposing to do with LA-ICPMS.