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ADAPTIVE MANAGEMENT OF THE COLORADO RIVER ECOSYSTEM BELOW GLEN CANYON DAM, ARIZONA: USING SCIENCE AND MODELING TO RESOLVE UNCERTAINTY IN RIVER MANAGEMENT

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ABSTRACT: An Adaptive Management program is underway in the Colorado River ecosystem below Glen Canyon Dam, Arizona. The focus of this effort is to identify dam operations and other treatments that can be used to protect natural resources in Grand Canyon while also meeting the operational needs of Glen Canyon Dam. The adaptive management process assumes that ecosystem responses to management policies are inherently complex and often unpredictable. Because of uncertainties associated with ecosystem complexity, the direction of resource response cannot always be predicted for proposed management actions. Uncertainties persist even when extensive, pre-action, monitoring programs provide data needed to develop predictive models intended to evaluate proposed actions. To respond to the challenge of protecting the natural resources of Grand Canyon, the Glen Canyon Dam Adaptive Management Program has used long-term monitoring of key resources, such as native fish, interpretive and predictive modeling exercises to evaluate monitoring data and management actions, and experimentation to examine restoration options for key abiotic and biotic assets in Grand Canyon. Under this approach, ongoing science continues to provide important information that modifies previous conclusions and helps to support more informed recommendations by resource managers. In addition, unexpected natural events such as extended drought, which may alter the most well planned experiment, have simultaneously provided additional opportunities for learning about ecosystem function. To support the Adaptive Management process, scientists are working closely with managers in using a combination of monitoring and interpretative modeling programs to track ecosystem responses to these field experiments. In this setting, learning about resource responses to flow and non-flow "experiments" is valuable, but only to the extent that it leads to resource benefits.
KEY TERMS: Colorado River; Glen Canyon Dam; Adaptive Ecosystem Management; Age-Structured Mark-Recapture; conceptual ecosystem modeling; sand bars; humpback chub

INTRODUCTION

An adaptive management effort is based on the premise that ecosystem responses to management actions are highly complex and often unpredictable. By embracing these uncertainties and approaching management actions as experimental "treatments," scientific outcomes can provide new information to managers regarding the range of possibilities for achieving resource conservation objectives. Similarly, if scientists approach model development with a willingness to admit uncertainties in predictive capability, then such research activities can also become learning opportunities for managers.

Following basin-wide development of water supply infrastructure (1930s-60s), impacts of Glen Canyon Dam operations on downstream resources of the Colorado River have been studied by scientists and engineers since the early 1970s (Figure 1). Despite this history of investigation, many uncertainties about the relationship between dam operations and river resources remain. In response to the persistent uncertainties, the U.S. Secretary of the Interior directed the Bureau of Reclamation in 1989, to conduct the first-ever retroactive environmental impact statement (EIS) on operations of a large dam. From 1990 to 1995, intense environmental studies focused on the influence of Glen Canyon Dam operations on native, endangered humpback chub *Gila cypha*, sensitive cultural preservation sites, sandy shoreline habitats and the concept of using artificial floods to restore sand bars. The concept of using controlled, high releases to restore sand bars was initially tested in 1996, and those experimental results prompted sediment scientists to question the basic strategies for sand bar restoration identified in the 1995 final EIS (see Wright et al., 2005, for a comprehensive summary of sand bar studies).

After the 1995 EIS was completed, other hypotheses about the influence of daily fluctuating flows and river temperature on the early life-history success of native and non-native fish have also been critically evaluated by scientists. In 1997, a Federal Advisory Committee comprised of stakeholders with varied interests in the river ecosystem was established to assist the U.S. Department of the Interior with adaptive ecosystem management implementation. In 2002, on the basis of reports

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from scientists that resources were not being improved under the new dam operating rules, the Glen Canyon Dam Adaptive Management workgroup recommended that new, post-EIS experimental studies be implemented to identify better options for achieving conservation objectives for the river ecosystem (Gloss et al., 2005; Wright et al., 2005; Rubin et al., 2002). The Grand Canyon Monitoring and Research Center (GCMRC) was created in 1995, to assist the managers by providing science information relating to the project. Experimental efforts are currently underway for both biology and sediment resources.

While new information from the river ecosystem science program has helped scientists and managers identify questionable hypotheses related to sediment conservation, adaptive management has also led to many new hypotheses about biological river responses to dam operations. The objective of this report is to promote information transfer about how strategies for ecosystem science (modeling, monitoring and large-scale experiments, particularly, as related to native fish conservation) are being used to support resource management in Grand Canyon.

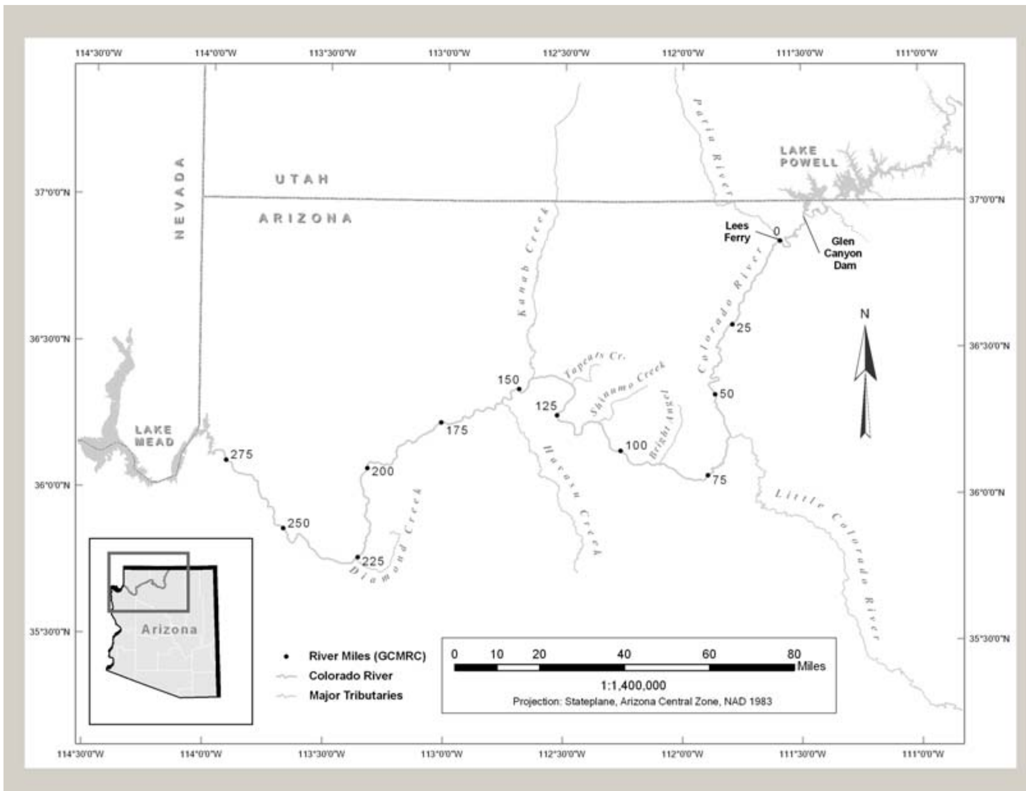

Figure 1: Colorado River Ecosystem, southwestern USA, with river miles shown below Lees Ferry.

MODELING AND MONITORING IN ADAPTIVE ECOSYSTEM MANAGEMENT

Conceptual Ecosystem Modeling

Following the 1995 EIS, a conceptual ecosystem model for the Colorado River in Grand Canyon was developed by the GCMRC and its science cooperators (see Walters et al., 2000). This effort was intended to identify gaps in understanding about how dam operations related to river ecosystem processes. The objectives for ecosystem modeling were to: 1) clarify key policy options and performance indicators (fishes, sand bars, etc.), 2) identify causal linkages between management options and resource indicators and 3) specify clearly why policy predictions based on synthesis of past data might fail by highlighting particular science gaps (helping managers and decision makers to “confront uncertainty”). The benefits of the conceptual modeling exercise were twofold: 1) it clearly identified that there was a critical need for diagnostic experiments and monitoring programs that would provide data to test hypotheses about sand and fish conservation related to the EIS proposed operations and 2) it more clearly identified the potential benefit of using experimental design and implementation to achieve the requisite “learning by doing” in an efficient timeframe.

The Grand Canyon conceptual modeling approach focused on existing monitoring programs and various theories on Grand Canyon ecosystem function. This exercise was highly successful in identifying data gaps where additional research was needed to provide insight into how management actions affected key Grand Canyon resources (Walters et al., 2000). Conceptual modeling also demonstrated the main value in simulating a complex ecosystem like Grand Canyon - where do cause-and-effect uncertainties exist with respect to both dam operations and non-flow elements of this unique ecosystem? Of critical importance, several questions about endangered humpback chub were identified through conceptual modeling: 1) what is a valid method for estimating population abundance and assessing population trends over time?, 2) what role, if any, do non-native fish play in humpback chub population dynamics?, and 3) how would native and nonnative fishes respond to a warmer river and (or) more stable daily flows and would such conditions affect native and nonnative fish interactions?

Native Fish Monitoring

Historically, the native fishes of Grand Canyon consisted of eight species: roundtail chub *Gila robusta*, bonytail *Gila elegans*, humpback chub, speckled dace *Rhinichthys osculus*, Colorado pikeminnow *Ptychocheilus lucius*, bluehead sucker *Catostomus discobolus*, flannelmouth sucker *Catostomus latipinnus* and razorback sucker *Xyrauchen texanus* (Gloss and Coggins, 2005). Prior to the completion of Glen Canyon dam in 1963, the Colorado River through Grand Canyon was a widely variable aquatic environment annually exhibiting large flow and temperature variation, high turbidity, and a unique native fish assemblage. The native fish that evolved in this system developed unique body morphology in this extreme environment including the aptly named “humpback” chub. About 80% of the native fish in the Colorado River are endemic to this river system and are found nowhere else. These endemic species are the focus of much concern by conservationists and those concerned with the preservation of native fish species. Today, only the humpback chub, speckled dace, bluehead sucker and flannelmouth sucker remain in Grand Canyon and the other four species are considered extirpated from Grand Canyon. The modern Grand Canyon fish community also contains a diverse group of nonnative warm water species (e.g., common carp *Cyprinus carpio*, fathead minnow *Pimephales promelas*, channel catfish *Ictalurus punctatus*, black bullhead *Ameivrus melas*) and cold water species (e.g., rainbow trout *Oncorhynchus mykiss*, brown trout *Salmo trutta*).

To estimate humpback chub abundance and evaluate population trends, monitoring programs for the species were expanded and rigorously evaluated in 2000-2004 (Kitchell et al., 2003). Fish populations are commonly monitored using a combination of tagging programs where fish are collected, tagged, and released. Often, age-structured modeling programs require that a sub-set of fish be sacrificed annually to determine the age-structure of the population. Because previous (1980’s to mid 1990’s) research programs had utilized tagging programs to evaluate basic aspects of life history such as migration patterns (Gorman and Stone, 1999) and because of sampling limitations placed on researchers relating to the imperiled nature of this species (undesirable to sacrifice fish for age sampling), a new original modeling approach was developed specifically for humpback chubs in Grand Canyon to provide insight into population abundance and trends. This modeling approach, termed Age-Structured Mark-Recapture (ASMR; see Coggins et al., 2006a) combined the historical (1980’s-1990’s) tagging data, with the more recent (2000-present) intensive tagging programs, in a framework similar to an age-structured model commonly used in fisheries stock assessment (Hilborn and Walters, 1992; Coggins et al., 2006a). The ASMR model has been very useful at estimating population size and in particular providing insight into the long-term trends in humpback chub populations, information that was not previously available to resource managers.

Using data from 1989-2002, Gloss and Coggins (2005) and Coggins et al. (2006b) used simple catch-rate data (number collected per minute of sampling effort) and modeling results from the ASMR and other models to document downward trends in humpback chub populations from the 1980’s until the early 2000’s (Figure 2). Data from 2003 through 2005, have recently become finalized and we have updated the ASMR model to include this new information which can be summarized as two points: 1) the catch-rate information from the native fish monitoring programs show increased catches for juvenile humpback chubs and other native fish in recent years (Figure 3) and 2) the ASMR modeling results are very encouraging and show that the adult humpback chub population trends appear to have stabilized over the last 7 years (Figure 2).

To demonstrate the value of our long-term monitoring programs, and to show how difficult it is to rapidly evaluate trends in humpback chub populations in response to management actions, we constructed a series of “retrospective analyses” to demonstrate how with each year of sampling, critical information is collected leading to updated conclusions (Figure 4). This analysis shows how as new information is collected each year (individual lines, Figure 4), population trend is updated. For example, considering data only through 2002, suggests a persistent decline in adult abundance. However, considering information through 2005, suggests population stabilization. This is because in recent years, with intensive monitoring efforts, only about 20% of fish age-2 and older are collected because of the inherent difficulties of collecting fish in the Colorado River basin. This “capture-probability” of 20%, while at first appearing low, is actually much higher than in most fisheries tagging studies (Pine et al., 2003) because of the intensive nature of the existing monitoring program. There is, however, a delay in the recruitment to gear, because the long-lived (20 + years) humpback chub must reach a minimum size before they are susceptible to capture and tagging. Eventual recaptures of tagged fish provide the data that inform our model, allowing for an annual update of the population estimate.

So why does it appear that humpback chub populations are stabilizing in Grand Canyon? One aspect of our ongoing adaptive management experiment is the removal of exotic fish, primarily rainbow trout (an experimental treatment from 2003 through 2006), near the Little Colorado River confluence (Figure 1). Rainbow trout are thought to compete with and prey upon juvenile humpback chubs, potentially reducing their abundance and ultimately reducing the number of adult humpback chubs in the population (Gloss and Coggins, 2005). While direct measures of rainbow trout predation on, or competition with, native fishes are difficult to make, we have so far observed concurrent increases in juvenile chubs and other native fish in this section of the river (Figure 3) and concurrent declines in rainbow trout between 2002 and 2006 (data not shown).

In addition, since 2003, the river ecosystem has experienced increasing water temperatures in the Grand Canyon portion of the Colorado River owing to prolonged drought conditions and low water levels in Lake Powell. These low water levels have allowed warm water to pass through the dam and into Grand Canyon as opposed to the normally cold water that enters the river from the dam when the lake levels are at normal levels (Vernieu et al., 2005). The drought has provided managers with the opportunity for a unique "natural" experiment where warm water in the river is more similar to the pre-Glen Canyon dam water temperatures. Though the observed warmer water temperatures benefit both native and exotic cool water species, like trout, the benefit to the natives may be more pronounced because the dam release temperatures have been much lower than their preferred temperatures. Warmer dam releases may also favor warm water exotics like channel catfish. Additional factors that may have supported stabilization of the Grand Canyon humpback chub population include low, summer steady flows of 2000, or near-shore habitat changes that resulted from experimental floods conducted in 1996, 1997, 2000 and 2004 (Wright et al., 2005; Rubin et al., 2002). While we are unable to differentiate which of these "treatments" could be leading to increased juvenile fish abundance (and possibly to stabilized adult population sizes), our monitoring and modeling programs have allowed us to measure these responses and present new hypotheses for factors that influence native fish populations in Grand Canyon.

CONCLUSION

The Colorado River ecosystem in Grand Canyon, Arizona, provides a unique opportunity to evaluate various policies proposed for river management. In this setting, modeling and experimentation have been identified as useful tools to help resolve scientific uncertainties about best management practices. Despite the mixed sediment results of the 1996, experimental flood, sediment scientists were recently allowed to conduct one test of an alternative option for achieving sand bar habitat restoration (Wright et al., 2005). Although it remains uncertain whether or not a flow prescription for dam operations exists for sand objectives, ongoing sediment research provides new information for managers to consider.

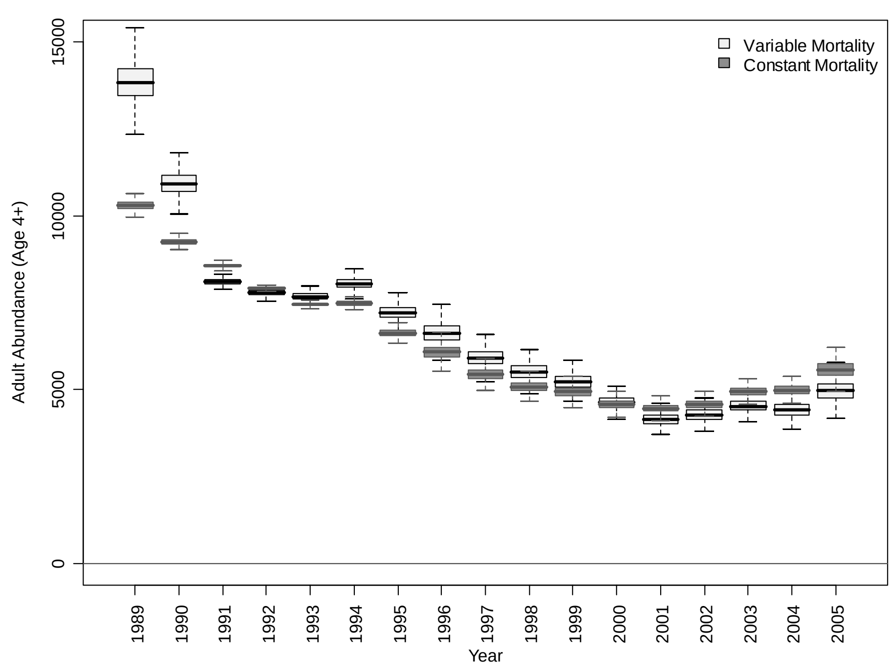

Figure 2. Adult humpback chub abundance estimates (1989-2005) for the Little Colorado River population from the age-structured mark-recapture (ASMR) model with mortality rate either constant or variable among years (for methods and assumptions, see Coggins et al., 2006a). Upper and lower bounds of plots are 95% Bayesian credible intervals.

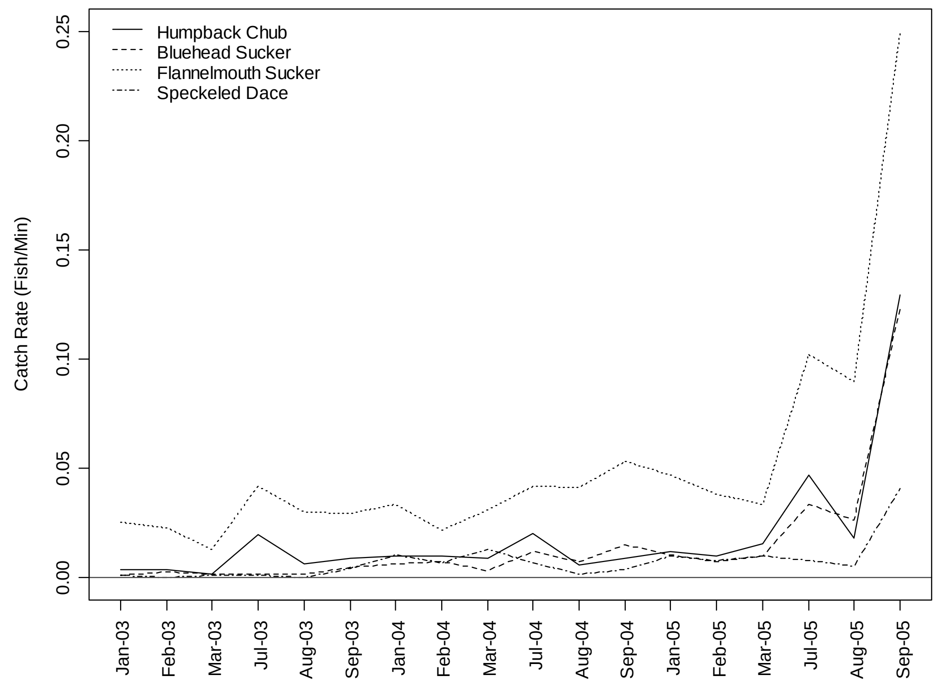

Figure 3. Relative electrofishing catch rates of native fish species (primarily juveniles) captured near the Little Colorado River confluence.

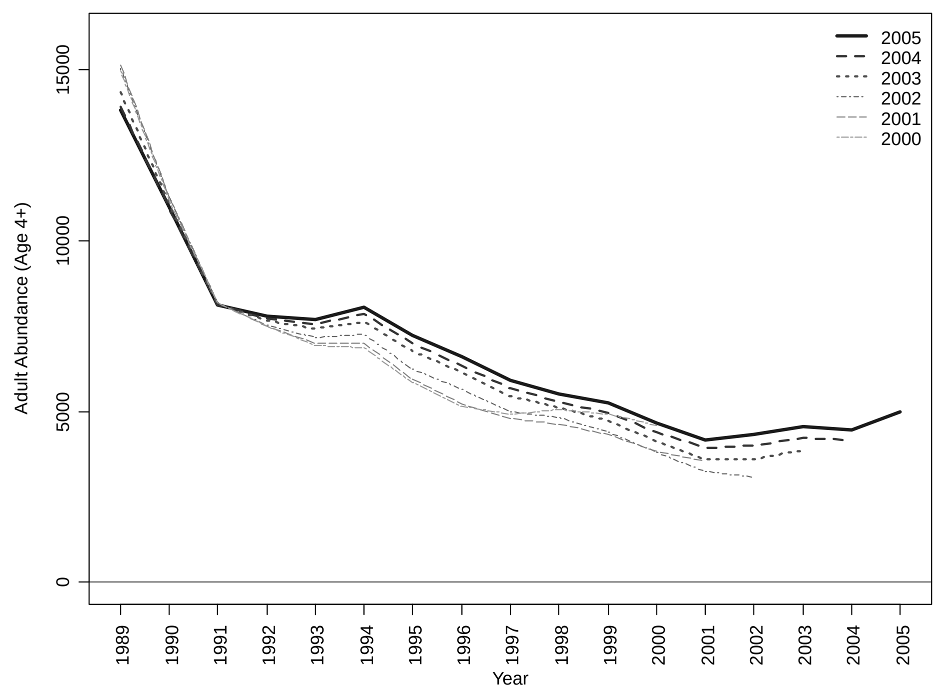

Figure 4. Retrospective analyses of adult humpback chub abundance. Each line depicts abundance estimates from variable mortality ASMR model and considering data between 1989 and the final year (final years 2000-2005, as identified in legend).

Development of new modeling methods for assessing the Grand Canyon humpback chub population (Coggins et al, 2006a and 2006b) is a significant contribution because these assessment techniques have provided insight into both the long-term and recent trends in humpback chub abundance. While this assessment program provides insight into trends, much more work is required to understand the complex mechanistic relationships between dam operations and native fish population dynamics. It is still unclear how exotic fish, temperature, and Glen Canyon Dam operations affect native fish. Resolving the complex interactions between these and other likely factors will require a commitment to well designed long-term experimentation and concomitant monitoring of cause/effect relationships among resources. Additionally, resolutions of these questions are critical to formulation of effective policies that lead to the persistence of these unique resources.

Key uncertainties regarding the effect of Glen Canyon Dame operations on downstream resources, such as sediment storage, humpback chub abundance, and cultural and recreational resources, remain. However, the Adaptive Management Program continues to provide managers with new information about management options and ongoing opportunities for experimental learning.

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