A Draft Prospectus on Integration of Biological and Physical Data Below Glen Canyon Dam, Arizona: Suggested Approaches for Assessing Biological Opinion Issues

[A Working Document Resulting from the August, 10-11, 1995, Integration Workshop held at the Hart Prairie Preserve, in Cooperation with the Glen Canyon Environmental Studies]

Prepared by an Ad-Hoc Interdisciplinary Integration Work Group

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CONTENTS

EXECUTIVE SUMMARY

A Draft Prospectus on Integration of Biological and Physical Data Below Glen Canyon Dam, Arizona: Suggested Approaches for Assessing Biological Opinion Issues

This document is a prospectus on core topics developed by an ad-hoc group of scientists to assist the U.S. Bureau of Reclamation in evaluating the operation of Glen Canyon Dam around specific Biological Opinion issues. Development of this prospectus was conducted through the Glen Canyon Environmental Studies as part of an overall integration effort. The core topics identified were (1) physical-habitat relations, (2) trophic dynamics, (3) population ecology of humpback chub, and (4) the role of science in adaptive management. Research questions, hypotheses, management implications, and data availability were identified for each core topic, and general approaches to integration of scientific data suggested.

The physical-habitat relations topic was intended to help provide a better understanding of possible relationships between geomorphology, sedimentology, and local to-basin scale hydroclimatology, and endangered species ecology in the Colorado River ecosystem through Grand Canyon. In addition, climate variability was identified as a significant forcing mechanism driving changes in habitat that likely influence the river ecosystem. Climate forcing affects both the regulated and non-regulated reaches of the Colorado River, as well as its regulated and unregulated tributaries. Climate variability, from decadal to-centennial or longer scales, is reflected within the drainage basin in ways related directly to the geomorphic framework, hydrology, and ecology of the river's ecosystem. Endemic species are unique, and have adapted life history strategies which allow them to survive in the Colorado River despite varied climate-forcing effects.

The endangered species most directly affected by changes in physical habitat include humpback chub (Gila cypha), razorback sucker (Xyrauchen texanus), southwestern willow flycatcher (Empidonax trailii extimus), and Kanab ambersnail (Oxyloma haydeni kanabensis), as well as the peregrine falcon (Falco peregrinus) and bald eagle (Haliaeetus leucocephalus). Existing dam operations or proposed changes under the Preferred Alternative of the Environmental Impact Statement (EIS) on the operation of Glen Canyon Dam, are likely to affect river geomorphology and the habitats of these species. However, the significance of such changes in physical habitat to survival of native and non-native fishes, remains unclear.

The trophic dynamics topic was designed to synthesize information on the food base and productivity of the river ecosystem, to determine the effects of dam operations on primary and secondary production, and determine the importance of food web interactions on fish population dynamics. The population ecology of humpback chub topic deals with life-history strategies and species interactions. A conceptual population model was proposed for identifying existing and missing data, and for helping to predict effects of dam operations on fish-population demographics, as well as responses by other species.

Adaptive management was identified in the Glen Canyon Dam EIS, as the process of gathering scientific information for management decision making on dam operations. A clear and effective means of communicating integrated scientific information to decision-makers is required for adaptive management to succeed. This integration prospectus is intended to foster and promote adaptive management of Lower Colorado River resources, through comprehensive use of scientific data, and development of a working relationship between scientists, managers, and other interested parties. It is also intended as a means of soliciting additional ideas about science integration related to freshwater ecosystems from other scientists and managers not yet involved.

INTRODUCTION

The following prospectus suggests some ways that scientific data from the Lower Colorado River might be integrated and synthesized to better manage resources below Glen Canyon Dam (GCD), Arizona. It is the product of many scientists with diverse backgrounds who voluntarily came together during summer, 1995, to discuss a common desire to synthesize biotic and abiotic information on the Colorado River ecosystem. This common interest focuses on the goals of resource preservation, restoration, and maintenance of biodiversity in large freshwater ecosystems, such as the Colorado River and other river systems.

This document symbolizes innovative efforts in the Lower Colorado River to bring scientists together for the purpose of discussing interdisciplinary river-ecosystem research, first using existing data, and eventually using new data obtained from long-term monitoring. New integrative approaches to investigation and management of freshwater ecosystems in the United States are presently being advocated at regional and national scales. At least six priorities have recently been outlined by scientists for freshwater ecosystem research: (1) ecological restoration and rehabilitation; (2) maintaining biodiversity; (3) modified hydrological flow patterns: (4) ecosystem goods and services; (5) predictive management; and (6) solving future problems (Naiman and others, 1995). All of these topics are applicable to management issues of the Colorado River ecosystem, and many of them are referred to specifically in this document.

Some general background information on how development of this prospectus occurred, and on this integration group's recent meeting and related activities, including some history on Colorado River research between GCD and Lake Mead, is also presented.

This document is not a plan, or a proposal for specific research, but represents the beginning of a cooperative process between the U.S. Bureau of Reclamation (BuRec), and the many cooperating organizations that have participated in scientific research on the Lower Colorado River since 1983. Discussing integration strategies is a natural result of scientific endeavors by researchers studying a complex river-ecosystem. Such scientific intercourse is generally encouraged globally, but is often restricted to single-discipline professional meetings, and often does not occur owing to language, philosophical, administrative, or geographic barriers. Overcoming these obstacles to scientific understanding is seldom easy, but is usually worthwhile. The scientists involved in this prospectus-development process came together to assert their belief that the value of new information gained through scientific integration is likely greater than the sum of individually-reported facts, databases, or even discipline-specific research interpretations.

The suggested integration approaches described in this prospectus center around management-driven issues which must be dealt with in a timely and cost-effective manner by BuRec. This prospectus is mainly the result of discussions and efforts by scientists, and reflects scientific responses to issues outlined in a recent Biological Opinion written by the U.S. Fish and Wildlife Service (1994). It is hoped that the results of this ongoing science-integration effort will assist managers in addressing concerns about endangered species preservation, provide a better understanding of the Colorado River ecosystem, and further promote interdisciplinary research in Grand Canyon.

BACKGROUND AND OVERVIEW

The Glen Canyon Environmental Studies (GCES) were initiated by the BuRec in 1982 to determine if perceived changes in Colorado River resources downstream of GCD were associated with hydropower operations at that facility. Dam impacts on downstream river resources were first described by Dolan and others (1974), following early studies contracted by Grand Canyon

National Park (also see Howard and Dolan, 1981). Concerns about downstream resource impacts were voiced strongly after 1980 when BuRec proposed changes at the GCD powerplant intended to increase power production, and the range of daily fluctuating flows on the Colorado River downstream. Although some effects of regulation were relatively obvious along the Colorado River, many other cause/effect relationships, and ecosystem linkages between GCD operations and the downstream river environment, still remained unclear twenty years after closure of GCD in 1963. To investigate the possible relations between GCD and downstream impacts, GCES, Phase I studies of Colorado River resources occurred from 1983 through 1988, involved many different organizations, and included studies of aquatic and terrestrial biology, avifauna, sediment mass-balance, tributary influences, hydrology, cultural resources, and recreational use.

Owing to above-normal precipitation in the Colorado River Basin from 1983 to 1985, daily fluctuating flows typical of hydropower production (the original intended focus of Phase I studies), did not occur during most of Phase I. As a result, effects on downstream resources solely from peaking powerplant operations could not be fully assessed. Nevertheless, much useful information was gathered during Phase I research, and results were presented in a series of single-discipline technical reports and publications (Bureau of Reclamation, 1988). Results from Phase I research confirmed that impacts to downstream resources had occurred since closure of GCD, and that these impacts were likely associated with hydropower operations, as well as flows outside of the typical fluctuating hydropower regime (e.g., reservoir spills such as the one that occurred in June, 1983). By the mid-1980's, fisheries studies had confirmed adverse effects from cold river temperatures on the endemic native fishes of the Colorado River (Bulkey and others, 1981; Hammen, 1982). Although the effects of Colorado River flows below GCD were studied extensively during Phase I, research designs were restricted mostly to single discipline studies, and lacked integration. To provide deeper insight into the implications of initial research, an integration group formed at the end of Phase I studies to summarize the results and conclusions, and a report was completed in 1989 (Bureau of Reclamation, 1989).

At the completion of GCES, Phase I, the Department of the Interior (DOI) requested that the National Research Council (NRC) evaluate the initial work, and provide recommendations on future directions. The NRC concluded that the GCES had met its overall goals and objectives, and that it was clear that impacts related to GCD operations could be reduced (National Research Council, 1987). In their review, the NRC also noted that the effectiveness of GCES, Phase I, would have been enhanced by an integration group established early in the research-planning process, and greater use of ancillary supporting studies from similar river systems.

Ultimately, the GCES, Phase I studies led to additional research and an expanded scientific approach in response to a number of management concerns. In 1988, DOI concluded that additional information was needed to comprehensively evaluate downstream effects from GCD operations, and called for further study, if dam operations were to be modified, so as to minimize downstream resource impacts. As a result, GCES, Phase II studies were initiated and completed in autumn, 1995. To ensure scientific credibility and coordination of research, Phase II studies were conducted under the direction and oversight of a senior scientist (Patten, 1991). As Phase II studies began, the DOI mandated an Environmental Impact Statement (EIS) on the operations of GCD. Phase I studies, available Phase II draft reports, and other information solicited from scientists were used to: (1) design and implement research flows during the first year of Phase II, (2) implement "interim" flows following cessation of research flows, and (3) evaluate seven proposed EIS operating alternatives. During preparation of the EIS, interim-flow releases at GCD were mandated to minimize downstream resource impacts. These limited daily-range flows began in August, 1991 and are now mentioned in the Annual Operating Plan for the Colorado River Basin. Interim flows will be retained until a record of decision is completed by the Secretary of Interior.

Phase II studies investigated many ecosystem-level responses of the Colorado River between GCD and Lake Mead, and included research on tributary effects, mainstem sediment transport, hydrology, water quality, limnology, geomorphology, aquatic resources, native and endangered species, recreational uses, cultural resources, and economics related to GCD operations. Phase II studies were relatively more comprehensive than earlier studies, but again lacked critical components of integration. Although most of the Phase II reports were still in progress as the EIS was written, conclusions from draft reports were incorporated into the final EIS to the greatest extent possible. Despite being centrally coordinated through GCES, most Phase II research reports completed in 1995 still require an expanded degree of scientific and technical integration to provide managers with comprehensive information relating river resources to dam operations. By the end of Phase II, it was clear that an adaptive management approach to decision making would guide some future operational changes at GCD, and would rely on fully-integrated, existing scientific information, if it were to succeed.

In 1992, Congress passed the Grand Canyon Protection Act (GCPA; P.L. 102-575), which mandated that science and future adaptive dam management be linked together. Adaptive management is a process outlined and recommended in the Glen Canyon Dam EIS (Bureau of Reclamation, 1995) to facilitate informed decision making related to modifying operation of GCD. This approach inherently depends on interactions between a Technical Work Group (TWG, providing scientific information about dam impacts on endangered species, cultural, and natural resources, as well as water and power resources), and an Adaptive Management Work Group (AMWG, scientists, managers, and others representing all interested parties engaged in informed decision making). Ideally, these two groups work together to decide how to modify dam operations to preserve and restore Grand Canyon resources, as directed by the Grand Canyon Protection Act (GCPA). The Glen Canyon Dam EIS also recommends that a research center be established to oversee long-term monitoring, and ensure that integration occurs as part of adaptive management. The integration process is identified as a key element to making informed decision making within a flexible management framework. In addition, protection of endangered species below GCD is required by the U.S. Fish and Wildlife Service through the Endangered Species Act of 1973 (ESA), and the means of enforcing that legislation has been outlined in the Biological Opinion (U.S. Fish and Wildlife Service, 1994), and included within the record of decision process. Thus, enforcement of legislation and modification of GCD operations can be linked through an evolving management process: adaptive management.

As described in the EIS, adaptive management is intended as a flexible tool for assuring compliance with the ESA as directed through the Biological Opinion (U.S. Fish and Wildlife Service, 1994). The GCPA, the "law of the river", cultural preservation requirements, ecosystem sustainability, and adaptive management all require extensive, well-integrated information on the interactions between dam operations and aquatic and physical resources of the Grand Canyon ecosystem. To meet these goals, an effective mechanism for communicating such information to decision makers (e.g., open and timely dialogue between TWG and AMWG participants) is required. Currently, for example, poorly-understood linkages between life histories of native endangered and nonnative fishes and their physical habitat requirements, make it difficult to predict how changes in dam operations might differentially affect fish species. Hence, adaptive management decision making needed to aid in the goal to remove jeopardy of humpback chub is somewhat hindered until such time that scientific integration begins. However, once integration occurs, successful decision making is not ensured unless information is effectively transmitted.

As Phase II studies concluded and final reports were submitted to BuRec, GCES and its cooperators were faced with the many complex aspects of eventually implementing adaptive management. The GCES group realized that more information was available from existing databases than was initially presented in most Phase II reports. Many critical linkages and relationships between river resources and GCD operations were not fully described by conclusions of single-discipline reports and publications. However, it was also recognized that additional information might be obtained through interdisciplinary debate, data sharing, and ongoing discussions among scientists. BuRec anticipated that future management issues would likely arise during adaptive management; particularly those related to endangered species and cultural resources. Unbiased scientific integration, in partnership with clearly defined management objectives, was deemed by GCES and associated scientists to be the likely means of answering questions related to Biological Opinion issues. Addressing those issues depended on full interpretation of existing data, combined with careful long-term monitoring. Recognizing this need, GCES and others initiated discussions on integration of diverse databases related to endangered species issues.

Integration was recommended in the EIS (Bureau of Reclamation, 1995, pp. 36-37) as one of the desired goals of a proposed monitoring and research center, but unforeseen delays in establishment of such a center meant that integration was also delayed. However, impending schedules for experimental-flow research, implementation of selective withdrawal structures at GCD, ongoing long-term monitoring, and pressing Biological Opinion issues demanded that integration begin as soon as possible, if informed Transition Work Group decisions were to be made in a timely manner. Presently, the GCES group provides a forum for scientific integration of some Colorado River data related to ongoing management needs, until a research center is established. Of most immediate importance, is integration of aquatic and physical data relative to GCD operations, as outlined in the Biological Opinion (U.S. Fish and Wildlife Service, 1994). These technical and management issues are mainly related to endangered-species preservation, impacts of experimental flows, thermal alteration of the river below GCD, ongoing endangered-species monitoring and research, and affects of seasonally-adjusted steady flows through Grand Canyon. The anticipated spring, 1996, experimental flood release from GCD provides one of the first opportunities to use integration approaches in the adaptive-management process.

Broader-scale integration, separate from the process described here, is also being initiated by GCES under direction of the group's senior scientist. That planned work attempts to synthesize all aspects of Phase I and II research on terrestrial, aquatic and geomorphic systems of Grand Canyon, as presently described in single-discipline reports. This larger-scale integration effort transcends the scope of the Biological Opinion related integration discussed in this prospectus, but can, and should, be linked to those larger-scale efforts. Hopefully, all of the integration efforts being developed by GCES will facilitate a smooth and effective transition to oversight by the future monitoring and research center. For the adaptive management process to work, scientists must provide decision-makers and resource managers with unbiased, integrated information that efficiently addresses key ecosystem and operation elements. Unintegrated information will likely lead to more confused decision making.

BEGINNING THE SYNTHESIS PROCESS

To begin achieving integration goals, GCES initiated a scientific consolidation of ideas by inviting a group of researchers with ongoing studies in the Grand Canyon to meet and discuss strategies for making better use of existing scientific data. This group was asked to debate and suggest potential integration approaches, and prioritize additional work required to address GCD operational issues, in light of the Biological Opinion (U.S. Fish and Wildlife Service, 1994). These group discussions included the impact of climatic variability in Colorado River systems management, effects of implementing the EIS Preferred Alternative, effects of possible, unanticipated reservoir spills, impacts of proposed experimental flows, implementation of selective withdrawal structures at GCD, and effects of seasonal steady flows on the river ecosystem.

A workshop-like meeting was convened in August, 1995, comprised of representatives from federal and state agencies, academia, the private sector, and Native American tribes (informally referred to here as the Integration Work Group or IWG). Owing to schedule and funding constraints, not all Grand Canyon researchers attended the meeting; however, those not present were, and are, encouraged to participate in the integration process. By design, only scientific researchers were involved in the first meeting, so as to intentionally minimize discussion of political and management issues. Later discussions were opened to topics such as the role of science in the adaptive management process, and use of scientific approaches, such as field and laboratory experiments to achieve management objectives. It was clear to the IWG, that effective transfer of science integration results to decision-makers was key to the success of adaptive management, and therefore could not be ignored.

The two-day meeting occurred on August 9-10, 1995 near Flagstaff, AZ (The Nature Conservancy's Hart Prairie Preserve). The first day of the meeting was spent reviewing the state of existing scientific data, and understanding (individual presentations on research conclusions) and debating points concerning future resource monitoring and Colorado River research. The second day was devoted to better defining key areas of recent research, such as endangered-species life history strategies and linkages to the geomorphic framework of the Colorado River, as well as GCD operations. To better focus discussions on science, three topics were accepted by the group for further exploration and debate. These core topics included:

1) **Physical-Habitat Relations**, which was further divided into subcomponents of geomorphology/sedimentology, and hydroclimatology;

2) **Trophic Dynamics**, dealing with productivity and food webs within the Colorado River; and

3) **Population Ecology of Humpback Chub**, which was subdivided in life history strategies, and interactions with other fish species.

In addition to these science integration topics, the IWG recognized the need to discuss the role of science, as well as the level of participation by scientists, in the adaptive management process. Based on the consensus that the adaptive management process has been extensively described in literature, but is inherently open to many misunderstandings and difficulties, the IWG agreed to outline a separate prospectus on the topic. It was agreed that a position statement on the role of technical scientific support in assisting the AMWG would be useful. This resulted in establishment of the final core topic by the IWG:

4) **The Role of Science in Adaptive Management: A Position Statement.**

This discussion group explored ways to ensure that the results of the basic science and integration would be communicated to managers and be used in decision making. In return, management concerns and objectives could be effectively communicated to scientists to further prioritize research efforts. Integration can improve understanding of the Grand Canyon ecosystem, but without adequate links between researchers and managers, integrated information cannot benefit decision making.

After agreeing on general needs for integration approaches, IWG scientists organized themselves into smaller groups to outline prospectuses suggesting integration strategies and potential hypotheses that should be considered during future Biological Opinion work. Group discussions occurred over several hours, and were followed by prospectus-outline development sessions during three one-hour modules. This strategy allowed most scientists the opportunity to participate in a variety of cross-disciplinary discussions.

OBJECTIVES

The integration process which began with the IWG is presented here, not as a definitive plan, or even as a proposal, but specifically as a prospectus written by a diverse group of scientists with expertise in a range of disciplines related to large rivers and impacts of flow regulation. This prospectus is symbolic of a unique scientific process in the Lower Colorado River. The integration effort developed voluntarily from a desire for greater knowledge, and evolved during an informal meeting of twenty-three scientists sharing a common desire to see improved management of the Colorado River ecosystem. It is hoped that the following integration suggestions will facilitate better use of scientific information toward the betterment of Grand Canyon resources, and will do so in ways that transcend institutional and agency boundaries.

In the spirit of cooperation that fostered interactions among scientists at the Fern Mountain meeting, the IWG acknowledged the benefits of developing working documents to help direct integration. These documents manifested themselves in the form of core-topic modules that are included in this prospectus. The modules describe and suggest ways in which scientific data may be integrated and interpreted, so as to provide the best available information to decision-makers entrusted with preserving resources in Glen and Grand Canyons. As with any working document, this prospectus should be revised in ways that reflect new knowledge and understanding of the Grand Canyon as monitoring and research continue. When new information is derived from long-term monitoring, experimentation, or breakthroughs in other disciplines or river systems, integration scientists will likely respond by modifying ongoing efforts. Ideally, this document, or ones like it, will evolve in ways that reflect the evolution of the ad-hoc IWG, and the development of a working relationship between the AMWG and the TWG participants.

Each core topic presented in this prospectus provides an introduction to the subject and describes some basic background for developing linkages with other core topics. Key research questions, hypotheses, and available databases are identified. These core-topic treatises are brief, by intent, so as to provide a focus on the important "big-picture" questions potentially facing TWG and AMWG members in the future, and to suggest possible ecosystem linkages that require further research and discussion if synthesis is to be achieved. Ultimately, this prospectus can and should be used as a scientific basis to help identify: (1) future core-research topics; (2) improved long-term monitoring strategies and goals; (3) approaches and methods for predicting and evaluating results of laboratory and field-scale experiments; and (4) approaches and methods by which scientists can be effective in assisting in AMWG decision making, based on clearly defined objectives.

Finally, this prospectus is intended to solicit ideas and suggestions from other scientists and managers not yet involved in integration. If encouraged and supported, the IWG, or similar integration efforts, can be an effective sounding-board for managers interested in interdisciplinary scientific opinion on certain management issues, including the implications of multi-level intake structure (MLIS) implementation at GCD; which resources should be monitored; and how should they be monitored. It is hoped that the integration process already underway through GCES may help facilitate open communication, and cooperation between managers and scientists alike, to provide more effective decision making during the adaptive management process.

PHYSICAL-HABITAT RELATIONS

Core-Topic A-I. Geomorphology and Sedimentology, Title: "Physical-Habitat Relations and Endangered-Species Distributions Along the Colorado River Below Glen Canyon Dam: An Opportunity For Integration"

Core-Topic Writers: T. Melis, M. Kaplinski, J. Schmidt, and R. Valdez

Principle Discussion Participants: M. Kaplinski, D. McGuinn-Robbins, T. Melis, R. Morgan, W. Persons, K. Redmond, R. Ryel, J. Schmidt, R. Valdez, G. Waring, and R. Webb

Introduction

Environmental studies on the effects of GCD operations on downstream river resources, suggest that physical attributes of endangered-species habitats may be a controlling factor in their distributions. Other controlling factors that influence ecology of native and non-native species include: food availability, river temperature, and distributions of predators. Many Grand Canyon researchers agree that integration of existing biotic and abiotic data bases, generated under the GCES, Phases I and II, could lead to the development of specific, testable hypotheses regarding these physical-habitat relations (PHR). Scientists and managers will be able to better manage endangered species, through operational changes at GCD once the specific roles played by habitat in species abundance are established.

At least six endangered species along the Colorado River between Glen Canyon Dam and Lake Mead are subject to GCD-operational effects, however, only four are presently being actively studied: humpback chub (Gila cypha); razorback sucker (Xyrauchen texanus); southwestern willow flycatcher (Empidonax trailii extimus); and Kanab ambersnail (Oxyloma haydeni kanabensis). Owing to the dynamic nature of Grand Canyon's climate and geomorphic processes, the habitats of endangered species are continually subjected to natural influences which are manifested as changes in the river's geomorphic framework; locally and on reach-wide scales. Continued physical changes in the river are expected, owing to geomorphic processes that are a natural part of Grand Canyon (e.g. floods, rockfalls, and debris flows), or that result from GCD operations (e.g. suppression of flooding, unplanned reservoir spills, prescribed experimental floods, and thermal effects from multi-level intake structure (MLIS) implementation).

Existing biotic data bases on endangered species require synthesis for PHR to be completely integrated with life-history strategies, and these data include: demographics, distribution, behavior, relations to associated species, reproduction, and habitat requirements. Abiotic data bases likewise require synthesis for integration to succeed, including: basin to-macro-scale characteristics controlling the geomorphic framework of the Colorado River, effects of tributary inputs (both fine and coarse sediment), relations of pre- and post-regulated hydrology to river resources, macro to- micro-scale characteristics of the river channel, its canyons, and its tributaries, present climate effects of regulation on the river, relations of paleohydrology and paleoclimatology to the present geomorphic framework of the system, and modeling results of sediment transport and hydraulics. Developing linkages between the above topics is a notably difficult task, but could likely be accomplished through ongoing integration and interdisciplinary research designs.

The potential for operating Glen Canyon Dam for endangered-species preservation is a real possibility, and one that requires consideration by managing agencies. However, appropriate responses on the part of the BuRec to the U.S. fish and Wildlife Service's Biological Opinion (U.S. Fish and Wildlife Service, 1994) partly depend on synthesis of PHR and endangered species life history information. Successful synthesis of these data will provide a clearer understanding of the existing relationships between GCD operations and endangered species life-history requirements, including habitat. This large task relies on a comprehensive understanding of species life histories, which by themselves will require considerable synthesis; for example a conceptual model for humpback chub ecology (the topic of a later section).

The geomorphic framework of the Colorado River, including its hydrology, geology and sedimentology, and its relation to aquatic and riverine habitats is only generally understood. For example, Valdez and Ryel (1995), hypothesized that a distinct, grouped-distribution of humpback chub aggregations in Grand Canyon occurs because of a unique combination of temperature and physical habitat conditions, in combination with specific life-history requirements for both adult and subadult life stages. However, such hypotheses remain untested.

Multidisciplinary integration of biotic and abiotic research began recently during final preparation of the GCD-EIS (Meretsky and Melis, 1995; and Melis and others, in press). While a great deal of information has been obtained about the geology and hydrology of the Colorado River and Grand Canyon, very little of that information has been incorporated into management decision making aimed at biodiversity and ecosystem preservation objectives.

Presently, local-scale integration efforts (referred to here as case studies), are providing a template for developing larger-scale projects. Examples of integrated research are now underway at two study sites. The first case study, at river mile 30, is being studied to investigate relations between mainstem humpback-chub reproduction, local geomorphic controls (warm spring locations relative to the morphology of localized debris-fan eddy complexes), and daily to-seasonally varied GCD operations. The second case study, at river mile 68, is being studied to better-understand and document the effects of an August, 1993 debris flow in Tanner Canyon on local river hydrology and geomorphology, trophic dynamics, and mortality of sub-adult humpback chub (Melis and others, in press).

Many other local to-reach-scale opportunities for integrating existing data related to Biological Opinion issues currently exist; including hydroclimatology and climatic-variability studies (see section on Hydroclimatology, A-II below). An experimental flow release from GCD, scheduled for spring, 1996, also offers an exceptionally unique opportunity to conduct additional local-scale and system-wide integrated river research. Integrated experimental designs that test hypotheses at the natural-system scale will contribute greatly to scientists' understanding of new and existing information. Results from such experiments, if related to decision makers in a clear and timely format, can be incorporated into GCD annual operating plans, thus serve to help in the accomplishment of management goals.

Selected Questions and Hypotheses

Integration-group scientists who participated in the August, 1995, meeting at Fern Mountain, developed a list of questions which begin to focus attention on developing the hypotheses and experiments necessary to identify specific roles of habitat relative to the endangered species of the Colorado River. The main questions posed by this group regarding PHR included:

A) Which physical and geomorphic attributes of the Colorado River in Grand Canyon presently control or limit distributions of endangered species downstream from Glen Canyon Dam?

B) How do identified GCD-operational effects on those physical/geomorphic attributes relate to long-term management of endangered species?

Neither of the above questions can be answered solely by assembling existing data bases, but the timely integration of such information is an essential first step toward true synthesis. A second step includes directing future data collection during long-term monitoring, so that these questions can be addressed through testing of a series of well-focused hypotheses. The questions listed above might ultimately be answered through a wide range of experimental and historical studies that link the documented interrelationships among endangered species, such as habitat, water quality, competition, predation, food bases, with other associated biotic factors such as aquatic productivity, population dynamics etc. Such a scientific process can only succeed through continued institutional support of innovative interdisciplinary efforts by a diverse group of scientists and decision makers who are committed to more holistic management of resources through integration. Such support will require that political actions by agencies and citizens to ensure that long-term fiscal commitments stand behind legislation to protect resources. The purpose of this prospectus is to begin the process of identifying the basic habitat-related questions and hypotheses that need to be rigorously tested, so that future decision makers will be better informed as they attempt to prioritize resources, and accomplish management objectives.

Many secondary questions and hypotheses were derived by the integration group from the broader questions posed above, including:

(1) Which endangered species below GCD will be affected by experimental dam releases (e.g., spike floods) because of altered PHR, and how will those effects manifest themselves?;

Associated Hypotheses:
H_o, Spike-flow effects will not significantly alter PHR in ways that change present endangered-species habitat distributions.
H_a, Spike-flow effects will significantly alter PHR in ways that change present endangered-species habitat distributions.

(2) How will the GCD-EIS "preferred alternative" affect PHR and endangered species distributions downstream from GCD?;

Associated Hypotheses:
H_o, The GCD-EIS "preferred alternative" will not significantly alter PHR in ways that change present endangered-species habitat distributions.
H_a, The GCD-EIS "preferred alternative" will significantly alter PHR in ways that change present endangered-species habitat distributions.

(3) Is it likely that future tributary-process effects (such as the LCR floods that occurred during winter, 1993 or the 1993, Tanner Canyon debris flow), will alter PHR under anticipated GCD operations; and if so, then how?;

Associated Hypotheses:
H_o, Continuing tributary effects (i.e., debris flows and streamflows), will not significantly alter PHR in ways that change present endangered-species habitat distributions.
H_a, Continuing tributary effects (i.e., debris flows and streamflows), will significantly alter PHR in ways that change present endangered-species habitat distributions.

(4) How will seasonally-adjusted steady flows (SASF), such as those described in the Biological Opinion, affect present PHR and endangered-species distributions?;

Associated Hypotheses:

H_o, SASF will not significantly alter PHR in ways that change present endangered-species habitat distributions.
H_a, SASF will significantly alter PHR in ways that change present endangered-species habitat distributions.

(5) Can PHR studies below GCD (macro-scale suitability evaluations) identify suitable locations in the river corridor into which endangered-species populations can expand, or which will support secondary populations, based on habitat-suitability analyses?; under future, altered river conditions?;

Associated Hypotheses:
H_o, Reach-scale geomorphic attributes of the Colorado River (debris-fan/eddy-complex characteristics, temperature, turbidity, shoreline types, substrate, etc.), are not significantly correlated with known habitat requirements or distributions of various life stages of endangered species below GCD.
H_a, Reach-scale geomorphic attributes of the Colorado River (debris-fan/eddy-complex characteristics, temperature, turbidity, shoreline types, substrate, etc.), are significantly correlated with known habitat requirements or distributions of various life stages of endangered species below GCD.

(6) How will implementation of MLIS at GCD alter PHR, and will those changes impact endangered species, non-native species, and associated species habitat availability and distributions below GCD?

Associated Hypotheses:
H_o, Implementation of a multi-level intake structure (MLIS) will not significantly alter PHR in ways that change present endangered-species habitat distributions.
H_a, Implementation of MLIS will significantly alter PHR in ways that change present endangered-species habitat distributions.

Management Implications

Integrated research can provide a better scientific understanding of PHR and endangered species ecology below GCD, and possibly throughout the entire drainage basin. As a result of interdisciplinary research, integration of existing data will also provide the Adaptive Management Work Group with valuable insights into developing better focused and refined long-term monitoring strategies. Success of integration depends mainly on the degree to which meaningful and accurate linkages are established between varied existing biotic/abiotic databases; a task that is inherently difficult, and one requiring, coordination, ongoing support, joint ventures by diverse groups of researchers, and flexibility and risk-taking in developing ongoing research strategies. Results from PHR - endangered species studies can also provide decision makers with some predictions of how altered flow effects may impact endangered species through habitat alterations, following natural or man-induced changes in the Colorado River below GCD.

Geomorphic and Sedimentologic Data Available for Integration

- **U.S. Geological Survey:** mainstem bathymetry data at numerous monumented cross-sections relating spatial and temporal changes in river-stored sediment to tributary processes and eddy/mainstem conditions; numerical models for predicting stage-discharge relations throughout the system, prediction of reach-averaged sediment transport patterns, and site-specific eddybedform topographic evolution; data on the frequency/magnitude data on tributary debris flows, and the effects of such flood processes on mainstem and tributary resources; morphology data on reach-varied shapes and sizes of alluvial debris fans that act to control recirculating flow, sedimentation and erosion within debris-fan/eddy complexes throughout the river's ecosystem;

- **Utah State University:** GIS-based geomorphic maps of Grand Canyon reaches showing historical relationships between river-flow patterns and spatial/temporal distributions of several geomorphic attributes, including sand bars;

- **Northern Arizona University:** GIS-based maps of pre- and post-regulated distributions of riverine vegetation. Data on the aquatic food base of the mainstem. Repeated topographic surveys of sand bars at thirty monitoring sites along the river reflecting sand-bar evolution from 1991 through 1995;

- **BIO/WEST Inc., and Arizona Game and Fish Department:** extensive databases describing life history and distribution, as well as physical-habitat relations of fish to the river, such as turbidity, backwater distribution, and distribution of shoreline-habitat types. Also included in the B/W GIS database, are radiotagged-fish movements relative to physical habitat parameters (i.e., bathymetry, substrate, and other habitat attributes like water quality, including temperature);

- **U.S. Fish and Wildlife Service:** various fisheries and habitat-related data for several Grand Canyon tributaries, including the Little Colorado River;

- **GCES:** life-history data on physical-habitat requirements and distribution of Kanab ambersnail and southwestern willow flycatcher. Detailed topographic data on stage/discharge relations and habitat availability at the LCR confluence, and at many other areas (i.e., 30-mile warm springs etc.). Mainstem model development for primary productivity. GIS site databases for many additional biotic and abiotic topics, and temperature data on mainstem sites;

- **NPS:** databases and experimental results of catastrophic sand-bar erosion processes in the Colorado River; data and maps on relations between tributary processes

- **Hopi Tribe:** data on the weather and hydrology of the Little Colorado River.

Some Suggested Future Integration Studies

Experimental-Flow Related Studies:

Use of aerial photography and on-site experiments designed to investigate spatial/temporal distributions, and morphology of backwater habitats immediately following experimental flows, and for modeling backwater habitat rejuvenation processes following the return to seasonally-adjusted interim flows. Water quality and recolonization of backwaters could also be monitored following experimental flows to study how these habitats develop between, during, and immediately after floods. This information may be correlated with fisheries data collected during transition-monitoring efforts to gain further knowledge on the importance of backwater to native and non-native fishes.

Documentation of changes in the physical conditions of debris-fan/eddy-complexes (sand bar development in eddies as related to available species habitats), and spatial distributions of shoreline types (including scouring of vegetated shorelines) within and between eddy complexes might be valuable if such information could be accurately related to known endangered species habitat requirements associated with such features. Changes in the distributions of available habitats should be documented in association with all experimental flows, and efforts should be made to understand how shoreline types, eddies, and other changing geomorphic features relate to species mortality, reproduction, etc., for species of interest.

Non Experimental-Flow Related Studies:

Ongoing monitoring of sand bar changes, and integration of information on relations between changing habitat use and patterns of channel storage of sand (relative to backwater habitat conditions, morphology of eddy-complexes, and changes in shoreline types used by various species and life stages). Past, and future data collected through Phase I, II, and transition-monitoring work, is available for integration with other databases. Continued sand-bar data collection allows continual re-evaluation of conceptual models of biotic/abiotic interactions related to known habitat requirements.

In general, it is important to continue adding to the existing knowledge on the river's hydrology and sedimentology, since these resources act together to form the river ecosystem's physical framework. However, all future geomorphic research and monitoring efforts should be designed and coordinated in ways that allow for interdisciplinary-type questions to be scientifically examined and tested through scientific methods that cross discipline boundaries. Integrated results must be made available to decision makers in clear and concise documents that address specific issues directly. Integration objectives should be clearly stated to researchers by managers before studies are carried out, so that management priorities are specifically addressed. Integration results must also be reported frequently enough so that decision makers have abundant opportunities to incorporate geomorphic information into management strategies aimed at biologic issues through adaptive management.

Reach-Scale Geomorphic Studies:

Beginning with a synthesis of historical, spatial, and temporal relations between backwater habitats, shoreline types, tributary inputs (i.e., debris-flow effects, and fine-sediment inputs), and river hydrology (stream gage records for mainstem and major tributaries), as interpreted from geomorphic mapping (1935-1990) and historic, repeat photography (1872-1995). For example, how has mainstem fish habitat changed in ways other than temperature and turbidity? Addressing these issues will allow all integration scientists to better understand what is and is not know about the physical attributes of the river system. Only then can other biotic disciplines integrate their data with the physical information available, and do so in ways that are meaningful for species management. Such a system-wide synthesis of physical data is comparable to developing conceptual models for species life histories.

For example, fisheries biologists may need to know if large debris-fan eddy complexes (features identified as adult life-stage habitat by humpback chub in recent studies), have changed significantly as a result of construction and operation of GCD. Changes in the morphology of eddies (related to sand storage throughout the river system), need to be compared with historical information on pre-dam habitat conditions, and then related to species requirements to whatever degree is possible.

Reach-by-reach comparisons of geomorphic attributes that influence the geomorphic framework of the river (i.e., reach-varied debris-fan styles, channel/eddy characteristics, backwaters habitats, shoreline types, etc.), might be synthesized and compared to conceptual ecologic models for species of interest. Many existing databases are available on such features and may be partially integrated with existing life history information relating to trophic information, or humpback chub ecology; as a start toward more in-depth synthesis..

As managers continue to prioritize resource preservation and restoration objectives, additional linkages between species ecology and habitat will likely arise. If an integration process is in place when additional unforseen questions arise, then issues and questions will likely be addressed and answered more efficiently than has formerly occurred. At the outset of integration and adaptive management, it is probably more important to form new working relationships, modes of communication, and ways of doing interdisciplinary studies, than it is to answer specific questions on relations between habitat, ecology, or dam operations that will ultimately have to be dealt with. With the development of this integration prospectus, at least the first steps of the process, and likely the most important ones, have begun.

HYDROCLIMATOLOGY

Core-Topic A-II. Hydroclimatology, Title: "Relating Hydroclimatic Effects to Physical and Biological Resources of the Colorado River below Glen Canyon Dam"
Core-Topic Writers: R. Webb, T. Melis, and V. Meretsky
Principle Discussion Participants: T. Melis, V. Meretsky, W. Persons, R. Pulwarty, K. Redmond, J. Schmidt, R. Valdez, and R. Webb

Introduction

The hydroclimatology of the Colorado Plateau affects a variety of physical and biological processes in Grand Canyon related to endangered species ecology. Flows in the Colorado River upstream from Lake Powell, the Little Colorado River (LCR), and other tributaries in Grand Canyon respond to regional and local-scale climate variability that is controlled by global-scale processes. These processes include general circulation patterns in the atmosphere, and Pacific Ocean sea-surface temperatures and currents (Liu and others, 1995; Rasmusson and Carpenter, 1982). Anomalous circulation in the atmosphere, and the global-scale phenomenon of El Niño in the Pacific Ocean affect climate and weather on the Colorado Plateau (Cayan and Webb, 1992; Andrade and Sellers, 1988), as well as the rest of the western United States (Kahya and Dracup, 1993 and 1994).

Runoff on the Colorado Plateau, particularly in ephemeral streams, responds to four general storm types: regional precipitation from dissipating tropical cyclones; warm-winter storms with embedded convective cells; cold-winter storms that bring mostly snowfall; and local summer thunderstorms. The occurrence of storms related to dissipating tropical cyclones tends to increase when El Niño conditions are prevalent and particularly when atmospheric circulation is sinuous. Warm-winter storms are related to both atmospheric circulation and El Niño, which jointly increase the probability of moisture being drawn from the tropical Pacific Ocean in winter. During El Niño conditions, winter storms increase in magnitude and frequency in the southwestern U.S., particularly during late spring in the Rocky Mountains (Kahya and Dracup, 1994 and 1993; Cayan and Webb, 1992). Localized summer thunderstorms over the Colorado Plateau are essentially random features that have not been related reliably to global-scale processes; if anything, failure of the summer monsoon in Arizona is partially related to El Niño conditions. Recent studies suggest that irrespective of storm type, precipitation intensity has been increasing during the twentieth century for unknown reasons, but might be related to anomalous conditions in the oceans and atmosphere associated with global warming (Karl and others, 1995).

The statistical relationship between oceanic, climatic and streamflow processes in the Colorado River basin is not well known, but climate effects are likely spatially varied throughout the region. However, high runoff during El Niño years (1983, 1993, 1995), and subsequent effects on Grand Canyon resources (e.g., increased humpback chub reproduction documented in the Little Colorado River (LCR) following winter flooding in 1993, and potential for unscheduled spills from Lake Powell related to wetter than normal conditions in winter and spring), suggest that knowledge of hydroclimatic forcing in the region could have important implications for management of biotic/abiotic resources downstream from GCD. Several areas of integrated river research relating to management issues have recently been discussed by Grand Canyon scientists. However, little attention has previously been paid to possible climate/habitat linkages below GCD, or the implications of such relationships. Additional research on possible relationships between climate, mainstem Colorado River flows and tributary processes may provide greater insight into the importance of physical habitat changes and their relation to endangered species ecosystem responses.

Suggested Areas of Research

• The recent period of intensive endangered-species monitoring and research (GCES, Phase I and Phase II studies) coincided with unusual 20th-century weather patterns in the southwestern U.S. Management decisions based on this research should be tempered with long-term climatic information to better understand whether the period 1990-95 was representative of long-term conditions within the Colorado River ecosystem.

The period of 1992-1995 is completely unique in the 20th century in terms of oceanic processes, general circulation, and climatic response in the western United States (frequency and characteristics of El Niño conditions). Although the 1983 El Niño was more severe, unusual climatic conditions from 1993 through 1995 were more prolonged, and in some cases, particularly in Arizona, the resultant flooding was larger. Implications of recent climatic conditions and related processes relative to endangered-species management are potentially great. For instance, the five years of data collected on humpback chub life history, including reproduction, recruitment, and population modeling, occurred during this unusual period. Before this existing information is used to modify operations of GCD, it is crucial to determine how relevant the recent study period is relative to the long-term conditions in the watershed.

• The hydroclimatology of the Colorado River, the LCR watershed, and other tributary processes, is an important factor in ecosystem processes related to trophic dynamics, endangered species life history traits, etc. The use of more robust forecasting models within the highly-regulated Colorado River system may aid adaptive management decision making by accounting for linkages between climate and ecosystem, and uncertainties associated with those links.

A cursory examination of the historic flood record of the LCR and other Grand Canyon tributaries, suggests that flooding in late spring may be common during El Niño periods, particularly when snowpacks within the LCR watershed are deep following above-average winter snowfall. Early spring flooding may be related to cessation of El Niño conditions. Drought is the typical response to La Niña in the southwestern U.S., which is the oceanic opposite of El Niño. If variability in spring flow in the Colorado River and its tributaries can be better explained through analyses of hydroclimatic relations, many predictions concerning productivity, sedimentation, species survival and other issues may be improved.

• Turbidity has important effects on instream productivity, and may increase survival of young-of-the-year native fishes by providing cover from predators. Sediment yield from the LCR, the Paria River, and ungaged tributaries is likely related to hydroclimatic forcing, and adaptive-management strategies for preservation of beaches and endangered fishes might be improved if a more comprehensive understanding of the timing of sediment influxes were available.

Mainstem and tributary sediment concentration of sufficient duration to significantly affect aquatic productivity, or fish survival might be related to summer monsoon rainfalls that are more-or-less evenly spread from July through September. In contrast, sediment transport from tributaries to the mainstem that significantly influence system-wide sediment storage, and ultimately, sand bar conditions, might be associated with sporadic summer storms, or 'burst' style precipitation events. Whether summer runoff is spread throughout July-September, or whether the Arizona monsoon fails, or is delayed until early fall, can be determined by studying local and regional hydroclimatic relations. The importance of turbidity for native fish species is poorly understood, but could be experimentally tested, and may warrant further research. Effects of sediment load on beaches and on productivity are currently under study, but little information on climate effects has been considered.

- Primary and secondary production in the Colorado River is influenced mainly by availability of light energy used for photosynthesis. The food web of the mainstem and its tributaries is therefore influenced over short and long periods by both sediment transport (turbidity, discussed above) and cloud cover. A more realistic aquatic productivity model than presently exists, could be developed if relations between the frequency of cloud cover (and sediment-laden floods) and hydroclimatic data was better documented. If accurate forecasting of such conditions could be incorporated into productivity predictions, then models would become more robust. Longer-range predictions of mainstem productivity would be useful to decision-makers faced with complex questions of food base/endangered fish relationships.

As noted above, the duration of turbidity in the Colorado River is probably related to the evenness of precipitation, particularly in summer when aquatic productivity is highest. Cloud cover may be highly correlated with turbidity and climatic forcing processes related to eastern Pacific Ocean conditions. These physical habitat factors affecting production in the river may be predictable through integration of regional hydroclimatology research in combination with present trophic dynamics studies.

- Better predictive models are needed for inflow into Lake Powell if systems models are to provide more accurate forecasts on releases necessary from GCD. Management of endangered species may depend heavily on conditions in Lake Powell as related to the potential for unscheduled spills, planned experimental flows, or water quality.

Planned release patterns from GCD may be totally disrupted by poorly-predicted high inflow to Lake Powell, as occurred in spring, 1983, and in 1995, when late spring snowfall at the end of an El Niño period caused releases to be higher than expected for an extended period. Poorly-planned releases can increase fish mortality by increasing water velocity and decreasing water temperature in areas used by young individuals. High releases also may affect other species less directly, and may disrupt the aquatic ecosystem in a variety of ways. Floods are a natural phenomenon in rivers, and many parts of the ecosystem may depend on them as a form of healthy disturbance. However, the timing and magnitude of unscheduled reservoir spills may occur out of sink with natural patterns of reproduction, etc. If inflow to Lake Powell could be more accurately forecasted about 6-10 months in advance, then adaptive management decision making aimed at protecting biotic/abiotic river resources could be better developed to respond to operational uncertainties associated with GCD. Moreover, planning for habitat-building experimental flows might be improved if the hydroclimatic forcings that increase runoff in the upper basin, and sediment influxes below GCD, were better understood and predicted.

Management Implications

Use of hydroclimatic relations and databases in preparing forecast models may significantly increase the ability of BuRec to plan releases from GCD, so as to protect endangered species of the Lower Colorado River. Better understanding of climatic relations related to tributary flows and to GCD operations increase the effectiveness of adaptive management decision making designed to preserve and restore river resources.

Available Databases

All of the data required for the integration effort outlined here are readily available, although aggregation and formatting of some databases may take considerable time. The U.S. Geological Survey collects the basic gaging and sediment data t hat would be needed for much of this work. The cooperative observer network of rainfall gages should be used to look at local climatic response as related to generation of runoff in watersheds on the Colorado Plateau. Data on the frequency and severity of El Niño conditions, as well as atmospheric circulation, are readily available from several sources. In addition, an interdisciplinary meeting of researchers interested in studying climate and its influence on related resources (PACLIM), is convened annually in Pacific Grove, CA. This meeting could provide a useful forum for scientists collaborating on climate-integration research in Colorado River Basin, and other river systems of interest.

TROPHIC DYNAMICS

Core-Topic B., Title: "Synthesis of Trophic Interactions Discussions at the Fern Mountain Symposium"
Core-Topic Writers: L. Stevens, and J. Shannon
Principle Discussion Participants: A. Ayers, M. Kaplinski, R. Marzolf, T. McKinney, J. Shannon, L. Stevens, G. Waring

Introduction

Numerous issues and questions related to trophic interactions in the Colorado River have been coming into focus, particularly over the course of the GCES Phase II and Interim Flows monitoring periods. This new understanding is based on a greatly improved understanding of the composition and distribution of the benthos and drift, and complex interactions between water quality, light availability, sediment transport, flow fluctuations on benthic production. This suite of studies has contributed substantially to basic understanding of benthic development in large regulated rivers, to the development of management options, and to the development of a cost-effective, long-term monitoring program that will help test ecosystem management concepts. In addition, these studies have helped direct research related to the use of planned flooding and thermal modification of the river to further improve ecosystem management. Ultimately, the goal of trophic research in this system is to develop integrated conceptual and quantitative models relating dam releases, geomorphology and climatology, to riverine productivity, trophic structure, and intra- and inter-trophic interactions. We recommend a scientifically-based, proactive approach to ecosystem management in this system, because failure to pursue understanding and monitoring of trophic interactions in this strongly "bottom-up" river will restrict adaptive management decision making, and lead to costly, inefficient and reactive ("What have we done wrong?") modes of ecosystem management.

Although an abundance of new information exists, numerous scientific concerns remain regarding integration and synthesis of these research and monitoring data. In addition, monitoring of some important resources needs to be standardized and synthesized more thoroughly, and other resources are being monitored on inappropriate schedules, or are not being studied at all. Some of the major topic areas include:

(1) Nutrient and other chemical dynamics in Lake Powell;
(2) Light limitations on riverine production, over time;
(3) The role of temperature on river assemblages and food web interactions;
(4) Tributary and mainstream nutrient dynamics and spiralling;
(5) The role of different size fractions of drift;
(6) Reservoir and riverine decompositional and microbial processes;
(7) Basic life histories and requirements of cornerstone species (e.g., Oscillatoria and Simulium);
(8) The role of spatial scale in geomorphology on aquatic food base development;
(9) The role of climate and climatic variability in development of the aquatic food base;
(10) Food web and ecological linkage between aquatic and riparian domains.

Synthesis of these components is required to develop Colorado River biodiversity and productivity models that can be used for management of endangered fish and wildlife in the river corridor, general ecosystem management, and to improve prediction of component and process interactions under different flow scenarios.

Most of the above topics include numerous individual sub-issues which require further discussion with managers before study plans can be proposed, to determine that the questions being addressed contribute to solving short-term and long-term management questions, or to inform managers of issues which they may wish to understand in greater detail. Such discussions will require managers to clearly define their objectives and goals.

Issues

Planned High Flows: Planned or unanticipated high flows may substantially alter benthic and other aquatic trophic levels, as well as alter backwater, marsh and sandbar riparian habitats. Some, but not all, of these resource issues have been addressed in the draft flood plan (Patten and others, 1994), and some resources are being monitored in a fashion that will permit accurate pre- and post-flood comparisons. However, important elements, such as drift and benthic colonization during the steady high flows of summer, 1995, have not been consistently monitored in the Grand Canyon.

Antecedent conditions prior to the proposed spring, 1996, experimental high flow will conditionally influence the impacts of that event on the river ecosystem. For example, constant high flows for more than four months during summer and fall, 1995, allowed Cladophora to colonize substrata at the 15,000 cfs stage, a zone not colonized by Cladophora since 1986. Subsidence of summertime high constant flows will strongly reduce Cladophora cover, and recovery may not be complete by late March, in time for the '96 flood flow. Benthic standing mass and drift patterns reported during the experimental high flow are likely to be quite different depending on whether the event is preceded by a normal or low-inflow year.

The proposed '96 experimental high flow will provide an opportunity to examine one or more return current channel backwaters in detail: how they reform, geochemical and biological development, and aggradation. These processes are discussed as basic concerns throughout the Glen Canyon Dam EIS, and the associated U.S. Fish and Wildlife Service Biological Opinion (1994), and are of obvious importance. Study of an experimental high flow would greatly enhance basic understanding of how backwater habitats are rejuvenated by floods, change afterward, and warm over the course of a year. Such a study should involve a consistent analysis of (preferably) three sites (one each in the Glen Canyon, Marble Canyon and Furnace Flats or Lower Canyon reaches) where rejuvenation of return-current channels is likely to occur. Analysis of topography/bathymetry before, during and after the high flow event should be conducted, as well as post-event monitoring of backwater and sandbar geochemical evolution, sandbar grain size analyses, site-specific climatology, 3-dimensional thermal measurement and modeling, phytoplankton and zooplankton development, productivity, and fish use. Such studies should be conducted in situ in a non-disruptive fashion so that the processes can proceed naturally. The result of this effort would be a site-specific physical/chemical/biological model that integrates geomorphic and biological interactions. It is hoped that such a study will be undertaken as part of the planned '96 high flow experiment because that event will be, in all likelihood, the only opportunity to study backwater evolution in the foreseeable future.

Thermal Modification: Construction of a multi-level intake structure (MLIS) to selectively warm the river may improve habitat conditions for native fish; however, the impacts of such a structure will be numerous, substantial, and many of them may be unanticipated. The largest impacts are likely to be on the aquatic lower trophic levels and on native-nonnative fish interactions. Synthesis of existing information will provide little insight as to potential impacts because thermal variability has not previously been an experimental option in this system. Even with detailed studies, unanticipated changes are likely, and contingency planning is recommended.

Long-term Monitoring: Implementation of an effective, cost-efficient long-term monitoring and research program will require synthesis of existing information and analysis of methodologies.

Methods should be based on clearly defined scientific monitoring questions, and data management should be an essential issue for each monitoring and research project. An overview of system dynamics should be developed to guide this process, and all monitoring and research should be contracted to the most highly qualified research teams to guarantee accurate and timely return of information on system development. These results should be synthesized into an annual report and presented by a qualified scientist to the Annual Operating Plan Group (AOPG) each year. The AOPG will be responsible for deciding whether and how to modify dam operations to mitigate impacts to the river ecosystem.

Conclusions

Synthesis of existing information on trophic interactions will help managers better understand the importance of food web interactions in population dynamics of species of concern. For example, Interim Operations have greatly altered macrophyte distribution downstream from Lees Ferry (Blinn and others, 1995). Also, constant high flows for four months during the summer of 1995 allowed algae to colonize substrata at the 415 m^3/s stage (a zone not colonized by Cladophora since 1986), and may have altered Cladophora and epiphyte distribution at depth. Reduction in discharge will greatly reduce algal cover and recovery at lower stages may not be complete before the planned high release in March-April, 1996.

These and related data may benefit planning of short- and long-term monitoring programs and future research, and may help identify critical data gaps. The synthesis process should be directed towards development of large-scale biological models, which presently do not exist. Further discussion between scientists is required to outline the structure of such models, and discussions with managers are required to ascertain the applicability of such models to management concerns, such as Biological Opinion issues, referred to in this prospectus.

Outline of Trophic Relationship Issues

(Superscript numbers represent high priority (1), moderately important (2) and long-term (3) data and synthesis needs)

(NOTE: We estimate that at least 3 FTEs are required for synthesis of this information by personnel who are fully "up to speed" on basic understanding of the river ecosystem, and perhaps twice as much time would be required for staff who are not intimately familiar with this ecosystem. Data base integration would require 2-3 FTEs at minimum. Integration with other relevant data bases would require at least 3 FTEs).

A. Potential Production:

1. Water quality and nutrient dynamics from Lake Powell[1]
    (a) . . . . Seasonal and depth related variability
2. Light limitations on production, over time[1]
3. Tributary nutrients[2]
    (a) . . . . Productivity of the LCR
    (b) . . . . Seasonality influences
4. River nutrient dynamics and spiraling[1]
    (a) . . . . Nutrient uptake over distance
    (b) . . . . Role of recirculation zones in geochemistry and nutrient spiralling
    (c) . . . . Nutrient dynamics in relation to low, medium and high flow regimes
5. GIS applications[3]

B. Resource Availability

1. Characterize benthic composition, standing mass[1]
    (a) . . . . Benthic changes over seasonal and inter-annual time scales
    (b) . . . . Distribution and production on system-wide and reach-wide bases
    (c) . . . . Epiphyte densities on <u>Cladophora</u> and other macrophytes
    (d) . . . . Flow impacts on benthos
    (e) . . . . Changing distribution of other macrophytes
2. Characterize habitat availability over time[1]
3. Aquatic (autochthonous) and terrestrial drift[1]
    (a) . . . . Quantity over space and time
        (i) Dissolved organic carbon
        (ii) FPOM
        (iii) CPOM
        (iv) Large woody material
        (v) "Bed load" carbon (e.g., John Gray bedload data?)
    (b) . . Zooplankton in Lake Powell, Colorado River mainstream and backwaters
        (i) Importance as a food resource
        (ii) Response rates under steady and fluctuating stage
4. Nutrient composition of food resources[2]
    (a) . . . . Dissolved organic carbon
    (b) . . . . FPOM
    (c) . . . . CPOM
    (d) . . . . Large woody material
    (e) . . . . "Bed load" carbon

(f) . . . . Lake Powell zooplankton

5. Delivery schedules and flow relations[1]
6. Distribution and composition of vegetated shorelines[1]
7. GIS applications[2-3]

C. Invertebrate, Fish, and Riparian Fauna Diets

1. Characterize diets (all species, all life phases)[1]
   - (a) . . . . Spatial and temporal variation
   - (b) . . . . Flow relations
2. Electivity[2]
3. Evidence of food limitation[1]
   - (a) Low humpback chub abundance in lower Canyon may relate to food or habitat limitations, increased predation or competition, or distance from main population center
   - (b) Rainbow trout condition decreases over distance from dam, and may be related to food or habitat limitations, increased predation or competition, or distance from main population center
     - (i) Total standing mass may not vary over distance
   - (c) . . . . Alternative hypotheses
     - (i) Competition
     - (ii) Predation
     - (iii) Disease/parasitism
     - (iv) Flow regime influences on habitat availability
4. Flow and turbidity impacts[1]
   - (a) . . . . On food availability
   - (b) . . . . On foraging success
5. GIS applications[2-3]

D. Habitats

1. Distribution of mainstream habitats and tributary input areas (using GIS)[1]
   - (a) . . . . Near shore/channel margin
     - (i) Vegetation type and influences
     - (ii) Structure
   - (b) . . . . Recirculation zone
   - (c) . . . . Backwaters
   - (d) . . . . Deep-water channel floor
2. Habitat availability under different flow regimes[1]
3. Resource availability in four habitats under different flows[1]
4. GIS applications[1-3]

E. Ecosystem Considerations

1. Overall trophic structure[2-3]
2. Food web[1]
3. Linkage within and between aquatic and riparian domains[2]
4. Other endangered species niches[1]
   - (a) . . . . Kanab ambersnail
   - (b) . . . . Southwest willow flycatcher

(c) . . . . Bald eagle
(d) . . . . Peregrine falcon

5. Conflicting habitat or ecological process needs[1-3]
6. GIS applications[2-3]

F. Management Considerations

1. Tools
    (a) . . . . Selective withdrawal[1]
        (i) Physical constraints
2. Impacts on benthos (composition, productivity, standing mass,distribution)
    (a) . . . . Novel species
    (b) . . . . Effects of mean and range of T

3.) Riparian climate
4.) River-borne disease
5.) Reciprocal impacts on Lake Powell
6.) Impacts on human fishing
    (a) . . . . Proposed experimental high flow[1]
        (i) Implement flood plan
        (ii) Examine resetting of nutrient spiraling
        (iii) Examine backwater evolution
        (iv) Downstream displacement of fish
        (v) Change in fish foraging success under high flows
    (b) . . . . Steady flow experiments[1]
        (i) Physical impacts (light and T)
        (ii) Drift
        (iii) Substrate grain size changes
        (iv) Continuing impacts on susceptibility of riparian vegetation
        (v) Bar erosion and backwater aggradation rate
    (c) . . . . Sediment augmentation[2-3]
        (i) Light limitations
        (ii) Impacts on native fisheries
        (iii) Impacts on recreational fisheries

Selected Hypotheses Relating to Trophic Relationships

The following broad-scale hypotheses are proposed to guide the synthesis process, and were selected as issues that may make the most substantial contribution to integration of physical and biological data in this system. Hypotheses are identified by letter-number combinations that indicate their link to the outline above. [AGF - Arizona Game and Fish Dept., NAU - Northern Arizona University, USGS - U.S. Geological Survey]

1. $H_{O\text{-}A}$: Nutrient dynamics are not differentially influenced by autochthonous versus allochthonous sources in the regulated Colorado River.

   $H_{A\text{-}A}$: Autochthonous sources play a disproportionately large role in trophic dynamics, while tributaries primarily influence the river ecosystem through suspended sediment concentration, and Lake Powell contributions primarily affect the Glen Canyon reach.

Data: AGF - Ayers and others, historic (i.e. Stone and Rathbun reports) and other GCES studies; BIO/WEST; Kubly and Cole (1970's); Angradi and Kubly (1994); Liebfried and others, (lower Grand Canyon); NAU - Blinn and others; other upper and lower basin studies.

Synthesis: Compile existing data and reexamine the hypothesis. Additional detailed sampling from LP to the Paria could reveal uptake under different flow regimes and seasons. 0.3 FTE.

GIS: Overlays of reach-based nutrient data with benthic algal distributions could illuminate large-scale patterns.

2. $H_{O\text{-}B1}$: Autochthonous benthic production does not vary across spatial scale in the regulated Colorado River.

   $H_{A\text{-}B1}$: Autochthonous benthic production varies between reaches, and between habitat types, and is increasingly patchy in its downstream distribution.

Data: AGF - Ayers and others, Hoffnagle, Persons, historic (i.e. Stone and Rathbun reports) and other GCES studies; BIO/WEST; Kubly and Cole (1970's); Angradi and Kubly (1994 x2); Liebfried and others, (lower Grand Canyon); NAU - Blinn and others, and students 1980's-present; Stevens (Museum of Northern Arizona, 1976); other upper and lower basin studies (i.e., Shiozawa, Ward, etc.)

Synthesis: Compile existing data and test the hypothesis. Note that this may require assumptions regarding comparability of data collection techniques. 0.3 FTE.

GIS: Experimental and historical studies should be cited in the GCES GIS, and analysis of standing mass in different geomorphic settings within GIS reaches could be mapped and analyzed.

3. $H_{O\text{-}B3}$: Benthic algal and invertebrate drift, and through-the-dam zooplankton drift (FPOM, CPOM), from the Lees Ferry reach is not important to downstream decompositional processes or fisheries.

   $H_{A\text{-}B3}$: Drift plays an important role in downstream bacterial dynamics, invertebrates (i.e. Simuliium arcticum) and fish.

Data: AGF (in Glen Canyon tailwaters), R. Antweiller (USGS), BIO/WEST, Blinn and

others, (NAU),
USGS Synoptic data (Howard), and diet data (above). Other studies exist outside the study reach in the upper and lower Colorado River basins.

Synthesis: Existing drift data should be compiled. Data regarding fish use of drift in the Colorado River should be reviewed (fish diet data, above). 0.5 FTE.

GIS: Applications to the GIS will primarily be related to archival of field data in GIS reaches, and to documentation of specific sites used for experimental or analytical purposes.

4. $H_{O\text{-}B5}$: The present (interim flows) seasonally-adjusted flow regimes do not influence the Colorado River benthos.

   $H_{A\text{-}B5}$: The benthos is affected by seasonally varying light and flow regimes, in turn affecting recolonization and productivity.

Data: AGF (in Glen Canyon tailwaters), R. Antweiller (USGS), BIO/WEST, Blinn and others, (NAU), USGS Synoptic data (Howard), and diet data (above). Other studies exist outside the study reach in the upper and lower Colorado River basins.

Synthesis: Analysis of existing data indicates relatively strong seasonal changes on algal production, with possible bottom-up consequences. Existing drift data should be compiled. Data regarding fish use of drift in the Colorado River should be reviewed (fish diet data, above). 0.5 FTE.

GIS: Applications to the GIS will primarily be related to archival of field data in GIS reaches, and to documentation of specific sites used for experimental or analytical purposes.

5. $H_{O\text{-}C1a}$: Native fish feed on a random assortment of food resources.

   $H_{A\text{-}C1a}$: Native fish diet reflects seasonal selectivity in relation to food availability.

Data: Upper Basin, Lower Basin?, BIO/WEST, AGF (Hoffnagle), Historical fish collections (stomach contents not yet analyzed): Museum of Northern Arizona, University of Michigan (Miller/Smith), Baton Rouge (Suttkus and others), Smithsonian (type specimen), Arizona State University?, AGF?

Synthesis: Compile existing data; analyze humpback chub, flannelmouth sucker gut contents; and prepare hypotheses for testing during the proposed high flow. 0.5 FTE.

GIS: Applications to the GIS will primarily be related to archival of field data in GIS reaches, and to documentation of specific sites used for experimental or analytical purposes.

6. $H_{O\text{-}C3}$: Autochthonous (benthic) and allochthonous (terrestrial) food resources are not limiting to native and non-native Colorado River fish.

   $H_{A\text{-}C3}$: The Colorado River fisheries below Glen Canyon Dam is at least occasionally food-limited, particularly during prolonged high flows, during turbid flows, and in the lower Grand Canyon.

Data: Upper Basin, Lower Basin?, BIO/WEST, AGF (Hoffnagle).

Synthesis: Compile existing data, and prepare hypotheses for testing during proposed high flow. 0.5 FTE.

GIS: Many reaches are under study and are in the GCES GIS, but the process of including benthic data or trophic interactions data requires further discussion. All site-specific or reach-related literature should be cited in GIS.

7. H_{O-C3}: Native fish distribution in the lower Grand Canyon is low because of chance and is unrelated to trophic interactions.

   H_{A-C3}: Predation, competition, lack of mainstream or tributary spawning habitat or lack of food limit native and non-native fish distribution and other trophic interactions in the lower Grand Canyon.

Data: BIO/WEST, AGF (Hoffnagle), Historical studies and fish collections (stomach contents not yet analyzed).

Synthesis: Compile existing data; prepare hypotheses for testing during the proposed high flow. 0.25 FTE.

GIS: Applications to the GIS will primarily be related to archival of field data in GIS reaches, and to documentation of specific sites used for experimental or analytical purposes.

8. H_{O-D1c}: Backwaters are unimportant to native and non-native fish and their development, and backwaters are not affected by high flows.

   H_{A-D1c}: Backwaters are important to larval and YOY native and non-native fish, and develop in a predictable fashion during and after floods.

Data: AGF (D. McGuinn-Robbins and Hoffnagle), BIO/WEST, Blinn and others (NAU), Parnell and Bennett (NAU). Other studies exist outside the study reach in the upper and lower Colorado River basins. Examine backwaters just downstream of LCR where larval humpback chub use is high, versus backwaters upstream from the LCR with low HBC use due to a lack of recruitment.

Synthesis: Existing data should be compiled. Data regarding fish use of drift in the Colorado River should be reviewed (fish diet data, above). In addition, this component requires a study to model geomorphic, geochemical and biological (productivity) evolution of 3 or more large return current channel backwaters during, and for 2 yr after, the proposed high flow. Knowing a great deal about a few backwaters will reveal much about how flow interactions affect backwater support of fish. This effort should also be coupled with system-wide monitoring of backwater distribution and tied to the experimental flood program.

GIS: Applications to the GIS will primarily be related to archival field data in GIS reaches, and to documentation of specific sites used for experimental or analytical purposes.

9. H_{O-E}: Present fluvial ecosystem trophic structure is equivalent to the pre-dam condition.

   H_{A-E}: Flow regulation (especially temperature and sediment transport changes) has decoupled the hydrograph from climate and resulted in higher diversity of selected taxa, and increased linkage between aquatic and riparian domains.

Data: Historic photographs, GIS-based sand-bar mapping data, observations and data;

GCES Phase I and II and interim flows data; Cataract Canyon and other rivers data.

Synthesis: Synthesis studies in progress.

GIS: Geomorphology and vegetation change data overlays; inclusion of rematched photo points (Webb and Melis data, as well as Schmidt's mapping data) could assist in this process.

10. $H_{O\text{-}F1a}$: Selective warming of cold-stenothermic releases from Glen Canyon Dam will have no effect on the downstream benthos and trophic interactions.

$H_{A\text{-}F1a}$: Selective warming of cold-stenothermic releases from Glen Canyon Dam will influence benthic composition, production and distribution, and have direct bottom-up consequences on native and non-native fisheries and other trophic interactions.

Data: Summertime distance-related data on benthos, diet and drift from AGF (Hoffnagle and prior studies), BIO/WEST, Blinn and others (NAU), Parnell and Bennett (NAU). Other studies exist outside the study reach in the upper Colorado River basin (e.g. Flaming Gorge) and in other systems. Lupher and Clarkson, and Lupher et al. and R. Muth laboratory and field studies data. Distribution of humpback chub in and around the Little Colorado River under different thermal conditions, and thermal studies by Protiva and others.

Synthesis: Existing data should be compiled (e.g., that of Protiva, Valdez, AGF and others). Experiments should be planned as part of the planned high flow and MLIS planning.

GIS: Some components can be monitored in a GIS context (e.g., seasonal thermal conditions in backwater and in the mainstream in the GIS reaches); however, numerous individual studies are required that may only be referenced in the GIS.

POPULATION ECOLOGY OF HUMPBACK CHUB

Core-Topic C-I: Life-History Strategies
Core-Topic Writers: R. Ryel, and R. Valdez
Principle Discussion Participants: R. Ryel, W. Leibfried, V. Meretsky, S. Leon, and R. Valdez

Introduction

The humpback chub (Gila cypha), described by Miller (1946), is a member of the minnow family (Cyprinidae) and one of three species of Gila reported from Grand Canyon. Miller (1946), Holden (1968), and Minckley and others (1986), surmised that humpback chub evolved from an ancestor common with Gila elegans about 3-5 million years ago. The population of humpback chub in Grand Canyon is one of six remaining populations of this endangered species. The Grand Canyon population is separated from the other five, located in the upper Colorado River basin, by Glen Canyon Dam and Lake Powell. The humpback chub is listed as endangered because of declines in distribution and abundance throughout its range (Valdez and Clemmer 1982), and has been given full protection under the Endangered Species Act of 1973, as amended.

Research has been conducted on humpback chub in Grand Canyon since the early 1980's. Much of the research was conducted under broad research programs including the Colorado River Fisheries Project (Kaeding and Zimmerman 1982, 1983), and the Glen Canyon Environmental Studies, Phase I (U.S. Department of Interior 1988) and Phase II (Valdez and Ryel 1995; Arizona Game and Fish 1994; Gorman 1994). In addition, much work has been conducted on the five populations of humpback chub in the upper Colorado River Basin (Valdez and others, 1982, Valdez 1990, Tyus and others, 1982, Karp and Tyus 1990, and McAda and others, 1994). Despite numerous studies, little has been done to integrate these findings into a comprehensive description of the life-history and ecology of the humpback chub. Particularly lacking is the development of a working hypothesis of the life-history adaptations of this species. This prospectus outlines the integration necessary to develop a better understanding of the life-history of humpback chub.

A better understanding of the life history of the humpback chub, as well as other native fishes in Grand Canyon (i.e., razorback sucker, flannelmouth sucker, bluehead sucker, speckled dace), will help to identify factors that limit populations under current operation of Glen Canyon Dam. Identifying these limiting factors will help scientists understand the relationships with and interactions of physical, chemical, and biological components and life history aspects. Physical habitat relations, trophic interactions, and effects of hydroclimatology are important aspects of the environment that profoundly shape the life histories of native fishes. Gaining a better understanding of life history requirements will enable scientists to identify and predict, from an integration of resource disciplines, the effects of a high spring release, steady summer flows, multi-level intake structure (MLIS), and flow criteria of the preferred alternative of the Glen Canyon Dam EIS.

Integration to Develop a Conceptual Model

The objective of this work would be to develop a conceptual model of the life-history adaptations and ecology of the humpback chub. This would entail using previous studies to develop a series of hypotheses describing the life history of the species. Integration would include combining data on demographics, distribution, movement and diet from the various studies. Synthesis from integration would be conducted to produce a conceptual model for this species.

The conceptual model would be used to identify life history traits common to all humpback chub populations, and traits critical to survival of the species. Life history traits that differ among populations would also be identified, and would be useful in ascertaining species plasticity and tolerance to environmental change and stress. The conceptual model, in conjunction with physical habitat descriptions, can be used to help determine the historical distribution and perhaps relative size of humpback chub populations throughout the Colorado River Basin.

Management Implications

The developed conceptual model for humpback chub life history would provide background information and a better understanding for evaluating management alternatives for Glen Canyon Dam operations. A consolidated and comprehensive description and conceptual model of the life history of the species would reduce the difficulty of trying to integrate information to make management decisions, and hypothesized effects of various management alternatives could more effectively be addressed. These hypotheses would test effects of various environmental aspects on factors that limit populations, including physical-habitat relationships, species interactions, trophic interactions, and hydroclimatology.

The conceptual model will also be useful in identifying aspects of life history where data are limited or lacking. Areas of minimal understanding can be assessed for importance and relevance, and future long-term monitoring and research programs can be more effectively designed to fill data gaps. Recommended future monitoring will be a product of the integration effort to help complete the life history description and conceptual model.

Data integration and conceptual model development will also be useful in designing and modifying the humpback chub monitoring program, and in interpreting monitoring data. Effective monitoring must be tied to an understanding of the life history of the species, and program elements which are necessary can be better identified and evaluated.

A conceptual population model may also be used to infer effects of certain existing dam operations or proposed operations. Understanding the dynamics of fish populations will help to develop hypotheses for evaluating a high spring release or a steady summer flow. This process is also valuable for identifying data gaps and for determining those informational needs that can be filled by field experiments or laboratory tests (e.g., swimming ability experiments for different life stages of native fishes at different acclimation temperatures and treatment temperatures that simulate field conditions).

Available Databases

Databases on humpback chub in Grand Canyon are predominately contained in reports or publications produced in conjunction with research in the Little Colorado River (Kaeding and Zimmerman 1982, 1983, Arizona Game and Fish Department 1994, Gorman 1994) and the mainstem Colorado River (Maddux and others, 1987, Arizona Game and Fish Department 1994, Valdez and Ryel 1995). Most of these reports and publications are readily available from the various research groups, and many are contained in GCES library collections. Further assimilation of these reports would be an initial step in reviewing prior research. Under GCES Phase II, much data on humpback chub is available in electronic form and also contained in reports. GIS data concerning distribution and movements of humpback chub, and physical habitat in Grand Canyon also exists. Databases for populations in the upper basin have been largely assimilated by the U.S. Fish and Wildlife Service (1989), and much information is also contained in reports and publications, but this information also lacks comprehensive integration. Hence, assimilation of life history data is one important aspect of developing a more comprehensive characterization of the life history of the humpback chub. Such assimilation would bolster integration of biotic and abiotic data for use by adaptive management to address issues of the Glen Canyon Dam Biological Opinion (U.S. Fish and Wildlife Service, 1994).

Core-Topic C-II: Species Interactions Between Native and Nonnative Fishes
Core-Topic Writers: W. Leibfried, and R. Valdez
Principle Discussion Participants: R. Ryel, W. Leibfried, V. Meretsky, S. Leon, and R. Valdez

Introduction

The interrelationships among and between fish species in the Colorado River in Grand Canyon is a research topic with a need for greater understanding. Miller (1961) hypothesized that in the early 1900's, prior to construction of Glen Canyon Dam (GCD) in 1963, native fishes were in serious decline, primarily because of negative interactions with introduced fishes. Leibfried and Zimmerman (1994) summarized available data for pre- and post-dam fish community structure and reached similar conclusions. Minckley (1991) proposed that the native fish community in Grand Canyon could be beyond recovery because of nonnative fishes and conditions from construction and operation of GCD. Mechanisms of these interactions are poorly understood, yet nonnative fishes may be partly responsible for the decline of other native fish communities in the southwestern United States (Douglas and others, 1994, Gregory and Deacon 1994). The question of how nonnative fishes interact with native fishes is important in understanding present conditions for humpback chub in the Colorado River below GCD, and how these interactions may change with proposed future adaptive management alternatives, varied climatic conditions and flood events.

Management Implications

Understanding the interactions between and among native and non-native fishes is important when determining the effects of dam operations on the aquatic ecosystem and hence, various species of fish. Operational aspects that favor competing or predaceous non-native fishes may adversely affect native fishes, while those aspects that disadvantage non-natives may benefit native fishes. Understanding these relationships is important if GCD is to be used as a tool, through the adaptive management program, to preserve and enhance native fish populations.

Selected Questions and Hypotheses

Four primary questions (Q) and null hypotheses (Ho) summarize interactions of native fishes with other fish species:

Q-1. What are the present effects of species interactions in Grand Canyon?
Ho-1. Interactions with nonnative fish species do not negatively impact the native fish community in Grand Canyon.

Interactions between native and nonnative fishes need to be identified and fully describe to determine all possible interactions and impacts. This can be best accomplished by examining the known life history and available data for each of the native and nonnative species currently found in Grand Canyon and associated tributaries or reservoirs, and incorporating this information with field investigations (e.g., stomach analyses, species interactions, etc.). A matrix analysis would allow for a full visual representation of species needs and potential conflicts with other species. Questions for future research and monitoring are "Can we determine species interactions at specific locations in Grand Canyon (i.e., LCR, mainstem, other tributaries, western Grand Canyon, Lake Mead inflow)?"

Q-2. What are the important species that interact with native fishes and are these interactions negative, neutral or positive?
Ho-2. Nonnative fish species do not currently interact with the native fish community in a negative way.

Those species, and the mechanisms involved, that most significantly affect the native fishes--particularly humpback chub--need to be identified. It is important to understand the mechanisms involved as to identify life stages of native fishes most affected, and to identify measures or strategies for minimizing these impacts. Incidence of competition, predation, and parasite vectors need to be identified. Known predators of humpback chub include brown trout, rainbow trout, and channel catfish; these relationships need to be further confirmed and quantified. Questions for future research and evaluation are "What are the risks associated with increased river temperatures (i.e., returning the river to near pre-dam conditions)?"

Q-3. Will future management actions, relative to GCD operations, increase or decrease these interactions?
Ho-3. Future management alternatives for GCD operations will not have a negative effect on the interactions of native and nonnative fishes.

The effect of future dam operations and resource management actions on fish species interactions also need to be determined and described. These evaluations should address implementation of a multi-level intake structure (MLIS), high spring releases, steady summer flows, operations under the preferred EIS alternative, and sediment augmentation. A matrix analysis may enhance simultaneous visual analyses of these effects, and provide a framework for identifying important aspects of management actions that should be isolated and compared to species needs and requirements. It is also important to consider GCD as a management tool. For example, a MLIS could be used to control cold water predators and sediment augmentation could control sight predators. Questions for future research and evaluation are "What are the effects of non-fish predators on the native fish community (i.e., avian fauna)?"

Q-4. Might fish interactions result in increased levels of parasites or pathogens in native fishes?
Ho-4. Interactions between nonnative and native fishes will not increase the levels of parasites and pathogens in the native fish community.

The importance of nonnative fishes as hosts of parasites and pathogens that can infect native species is poorly understood. A number of nonnative parasites have been reported from native fishes in Grand Canyon, particularly humpback chub, most of which were likely introduced into the system by nonnative fishes. Most notable are the parasitic copepod, Lernaea cyprinacea, and the Asian tapeworm, Bothriocephalus acheilognathi. Insufficient information is available on the incidence of these parasites and the level of infestation for individuals and populations. Furthermore, little is known of the effect of these parasites on fish health. Questions for future research and evaluation are "Will the native fish community be enhanced by proposed management actions?"

Integration

Data integration utilizing aspects of trophic dynamics, geomorphology/sedimentology and climatology may provide an avenue for greater understanding of species interactions in the Colorado River in Grand Canyon. Experimentation with water temperature, flow, predation, and turbidity, both in the lab and field, may enhance our understanding of species interactions under various physical conditions. The 1996 experimental flood release from GCD may also provide valuable information on species interactions during and after the flood event.

Available Databases

Information on predam interactions between humpback chub (as well as other native fishes) and nonnative fishes is nonexistent, and it is difficult to describe the extent and significance of these interactions. Data on species interactions from other rivers in the Colorado River Basin should provide valuable insights to these interactions. Fisheries studies conducted on the upper Gila, Upper Verde, and Upper Salt Rivers in Arizona (Douglas and others, 1994), the Virgin River in Utah (Gregory and Deacon 1994), and parts of the Green, Colorado and Yampa Rivers in the Upper Colorado River Basin (Tyus and others, 1982, Valdez and others, 1982, Ruppert and others, 1993) may provide useful data. Data concerning species interactions since the construction of GCD are limited to sympatry, comparative food habits, and predation. These data exist in reports from the Colorado River Fisheries Project, and GCES, Phase I and Phase II. Only some of these data are available in an electronic medium, and most of these data still require integration to be fully synthesized.

Outline Developed for Core-Topic Prospectus: Population Ecology of Humpback Chub in Grand Canyon: Life-history Strategies and Interactions With Other Fish Species
Principal Discussion Participants: R. Ryel, W. Liebfried, V. Meretsky, and S. Leon

C-I. LIFE HISTORY STRATEGIES

A. Introduction
1. Taxonomic overview of humpback chub
2. Evolutionary perspectives of Gila in Colorado River
3. Population status of humpback chub

B. Review of available databases
1. Grand Canyon pre-GCES studies
2. Grand Canyon, GCES I and II
3. Upper Colorado River basin studies (Black Rocks, Westwater, Cataract Canyon, Yampa Canyon, Desolation/Gray Canyon

C. Integration to develop life-history conceptual model or series of hypotheses concerning life-history strategy
1. Demographic data
   a. Age-specific survival rates
   b. Fecundity
   c. Population estimates
   d. Length frequency and age distributions

2. Distributional and movement data
   a. Identify limits of various populations/aggregations
   b. Evaluate intra/inter population movements
   c. Identify metapopulation dynamics

3. Diet and feeding strategies
   a. Define chub diet by age group
   b. Relate diet to available food items

D. Apply model of humpback chub life history to existing and historical populations
1. Identify elements of life history common to all chub populations
2. Identify elements of life history different between populations
3. Compare life history of present population of humpback chub with historical population, and populations in other regions of the basin

E. Integrate findings with dam operation alternatives to aid in predicting effects
1. Evaluate various flow alternatives on various life stages and processes
2. Evaluate multi-level intake alternatives on various life-stages and processes
3. Evaluate sediment augmentation on various life stages and processes

F. Recommendations for future evaluation and work
1. Integrate findings into monitoring program, including review process of monitoring program
2. Identify additional studies that would be important in understanding the life-history of humpback chub

C-II. SPECIES INTERACTIONS

A. Introduction
1. Historical/predam interactions
2. Historical accounts of species composition from early explorers and river runners
3. Can we recreate the predam species interactions from the information available today?

B. Review of available databases
1. Historical accounts
2. Early research
3. Recent research
   a. Museum of Northern Arizona
   b. GCES I and II
   c. Other university data

C. Build hypotheses around following questions
1. What are the present effects of species interactions in Grand Canyon?
2. What are the important species that interact with native fishes and are these interactions negative, neutral or positive?
3. Will future management actions increase or decrease these interactions?
4. Might fish interactions result in increased levels of parasites or pathogens in native fishes?

D. Integration
1. Combine, synthesize, and analyze all databases that may contain data germane to species interactions.
2. Summarize species interactions for various reaches and seasons in Grand Canyon.
3. Using geomorphic and biological data can we evaluate how dam operations might increase or decrease species interactions?
4. By integrating temperature modeling and biological data can we hypothesize the effects of future management actions (i.e., selective withdrawal, steady flows etc.)?

E. Research and Evaluation
1. Can we determine species interactions at specific locations in Grand Canyon (i.e., LCR, mainstem, other tributaries, western Grand Canyon, Lake Mead inflow)?
2. What are the risks associated with increased river temperatures (i.e., returning the river to near pre-dam conditions)?
3. What are the effects of non-fish predators on the native fish community (i.e., avian fauna)?
4. Will the native fish community be enhanced by proposed management actions.

ADAPTIVE MANAGEMENT AND THE ROLE OF SCIENCE AND SCIENTISTS

D. Core-Topic Title: "Adaptive Management Working Group: Summary Report on Integration Process and Needs"
Core-Topic Writers: R. Pulwarty, R. Marzolf, and T. Melis
Core-Topic Draft Reviewers: W. Leibfried, D. McGuinn-Robbins,W. Persons, and D. Wegner

Introduction

It is the purpose of this section to provide some background on the concept of adaptive management, and to outline the needs and goals of an ongoing role for scientists and scientific information in the adaptive management process. Adaptive management (hereafter AM), is an approach to natural resource decision making that embodies a straightforward imperative:

- if human understanding of nature is imperfect, then policies and management activities are experimental, and should therefore be designed to produce usable lessons.

AM operates on scales compatible with natural processes, is cognizant of nature's time frames, recognizes social and economic viability within functioning ecosystems, and is realized through effective partnerships among private, local, state, tribal, and federal interests.

The concept of learning from adaptive environmental assessment and management originated in the work of Holling (1978), and Walters (1986). These workers explicitly included a social process of dialog in combination with modeling and simulation to drive management actions. Thus, the fact that results obtained merely by studying undisturbed systems cannot simply be extrapolated to managed and operational settings, is acknowledged (Kessler and others, 1992). The primary example of development and implementation of an AM program occurs in the Columbia River Basin of the Pacific Northwest, within the context of the largest fish and wildlife recovery and enhancement program in the history of the United States. A comprehensive analysis of the formulation and evolution of this program is given by Lee (1993) and in reports of the Northwest Power Planning Council (1994).

The Role of Adaptive Management

AM originates in a comprehensive, ecosystem perspective, in which interactions among components of the natural environment are highly structured, and behavior of the system as a whole is rich in surprise (Lee, 1991). The characteristics of ecosystems which provide a basis for ecosystem management are complexity, scale, uncertainty and recognition of humans as part of ecosystem processes. In response to these characteristics, ten dominant themes of ecosystem management have arisen in the literature (Grumbine, 1992; Clark, 1993). These can be summarized as considerations of:

(1) **Hierarchical Contexts** - e.g., relationships, connections, and linkages at all scales;

(2) **Ecological Boundaries** - that necessarily cross administrative and political boundaries;

(3) **Ecological Integrity** - protecting biodiversity and the ecological patterns and processes that maintain diversity (e.g., conservation of viable populations of native species, maintaining natural disturbance regimes such as flooding, etc.);

(4) Data Collection - habitat inventory and classification efforts, better species management through use of existing baseline data and knowledge;

(5) Long-term Monitoring - the collection of data in ways that determine significant changes in resource status, and help provide new knowledge about ecosystem responses;

(6) Interagency Cooperation - federal, state, tribal, and local agencies, as well as inclusion and mediation of private parties with conflicting legal mandates and management goals;

(7) Organizational Change - structure, issue frames, modes of operation - These can range from the straightforward (forming a Technical Work Group), to the complex (changes in norms, altering power relationships, etc.);

(8) Humans in Nature - Understanding how humans influence and are influenced by ecological patterns and processes;

(9) Values - definition of goals, issue frames, etc., and;

(10) Adaptive Management.

Of these, the dominant themes least referred to in the literature are organizational change, values, and AM. Primarily, biologists and other scientists tend to underestimate: (1) the policy implications of changing power relationships, and (2) the complexities of blending diverse human values into management decision making (Clark, 1993). One major aim is to increase the flexibility of any system or population to adapt to or recover from unforeseen consequences or 'surprises' (i.e., exercise resilience). The AM approach makes explicit admission of the fact that while risk may be quantified, uncertainty is not, and so requires careful examination of assumptions and alternatives. AM incorporates a short-term strategy of protecting critically-rare elements of biodiversity, with a long-term strategy aimed at maintaining or restoring key ecosystem processes. AM has also been referred to as cumulative management policies and practices that improve society's understanding of ecosystems over time, and feed this information and support back into the management decision-making process (see Wilderness Society).

Adaptive Management as Embodied in the Operation of the Glen Canyon Dam Final EIS

Distributions of endangered, and other native fish in Grand Canyon are commonly thought to be limited by cold, clear-water releases, and large daily flow fluctuations associated with GCD operations. Other factors that likely influence such distributions include: the presence of non-native fish acting as competitors or predators; limitations on food availability; climate variability; presence of high dams; etc. However, uncertainty remains regarding details on the impacts of GCD operations on fishes (Valdez, Masslich and Leibfried, 1992). The Glen Canyon Dam EIS lists the benefits of seasonally adjusted steady flows as the only short term alternative having potential impacts for major (but uncertain) increases in humpback chub populations. This potential increase is based on the assumption that steady flows would be more similar to predam conditions than other presently-proposed EIS alternatives. Such flows are thought by some managers to be key because they will ease tributary access for native fish, increase the aquatic food base, and expand rearing areas for young fish. There has, as yet, been limited opportunity to study the combination of effects of low, steady flows during summer and fall, with higher steady spring flows (which may be critical to native fish).

It is estimated that future research flows, designed to meet the study objectives outlined in the EIS around this issue, may require as many as 5 low flow years (about 8.23 maf). It is uncertain as to how many years it would take to complete the recommended research program. However, it is clear that agreement can be found around two basic views: (1) the ecosystem resource-response phenomena being influenced by dam operations are occurring on time scales better measured in decades than in years; and (2) these phenomena are tied to hydrologic, geomorphic, and biological processes that have been changing, and will continue to change (Marzolf, 1991).

The Glen Canyon Dam EIS recommends the initiation of an 'adaptive management process' (BuRec, 1995, pp. 34), whereby the effects of dam operations on downstream resources would be assessed and the results of those resource assessments would form the basis for future modification of GCD operations. The AM program was designed to provide an organizational process through which cooperative integration of dam operations, resource management, long-term monitoring, and ongoing research, consistent with the mandates of the Grand Canyon Protection Act of 1992, could be accomplished. Issues considered in detail along with AM were: monitoring and protection of cultural resources, flood frequency reduction measures, prescribed beach habitat-building flows, establishment of additional populations of humpback chub, further studies of selective withdrawal implementation at GCD, and economic and physical considerations related to emergency exception criteria for GCD operations. A key component of the AM approach is to test the assumptions under which these management 'experiments' are to be carried out.

The AM program proposed for GCD is composed of three equally balanced elements: a technical process (Technical Work Group), an administration coordination process (Monitoring and Research Center), and a review process (Independent Review Panel). These three entities are intended to provide the information needed in the AM decision-making process (AM Work Group) which is then evaluated by the Secretary of the Interior (Wegner, 1995). The principles that guide the design and intent of the AM program and process, as outlined in the EIS, are:

- monitoring and research programs should be designed by qualified researchers in direct response to the needs and objectives defined by management agencies;

- a process is required to coordinate and communicate management agency needs to researchers and to develop recommendations for decision making;

- a forum is required for the transfer of monitoring and research investigation results to the management agencies; and to develop consensus on management responses to information on affected resource conditions, trends, processes, and prioritization of actions;

- all monitoring and research programs in Glen and Grand Canyons should be independently reviewed; and

- independent parties identified in the Grand Canyon Protection Act of 1992 should be given the opportunity for full and timely participation in proposals and recommendations that come out of AM.

Each of the above principles requires management, maintenance, prioritization, and integration of diverse information found in varied data bases, in concert with clear mechanisms for resolving disputes. Under the AM program, it is expected that BuRec would continue to allocate funds for administration, long-term monitoring, ongoing research, and data management, as outlined in Grand Canyon Protection Act (Sects. 1807, 1808). Funding for other management actions would be the responsibility of the agency administering the affected resources. The AM Work Group will be required to submit an annual report to the Department of the Interior on the state of the Grand Canyon riverine ecosystem's health, and to identify any specific recommendations for dam operation changes that should be considered (Wegner, 1995).

The major concerns related to AM and expressed in the "Comments and Responses to the EIS," centered on:

• Legal mandates (Grand Canyon Protection Act, Endangered Species Act, National Environmental Protection Act, and the National Historic Preservation Act);

• Definition and organization of AM Program;

• Definition, organization, and validity of long-term monitoring and research experimental designs.

If AM portrays resource work as a continuous learning experiment, then issues will naturally arise that reveal more effective ways that managers can use new information gained through research. As ways in which managers use and misuse information becomes more clearly understood, the effective use of new scientific information should increase. The next section generally outlines some of the potential problems involved with using AM procedures.

Lessons From Past Adaptive Management Experiences

The AM Work Group should provide a forum where key hypotheses and experimental designs are critically considered. The group should also allow interested parties to access new information, and to participate in decision making. The notion that we are willing to take dramatic steps to learn (like creating control cases, and then departing radically from them for testing purposes), can be exceedingly problematic in a high stakes setting (Volkmann and McConnaha, 1993). The high value placed on learning, held by most scientists, ignores the fact that in some situations ignorance has value when viewed as an opportunity to gain new knowledge. In the short term, 'good' science becomes that which supports one's favored position. Short-term economic benefits of resource development may be obvious, however, the benefits of environmental recovery over the long-term, are too often easily discounted.

A major hurdle occurs in the accommodation of biological risks and political considerations, while taking an aggressive approach to learning and implementing approaches based on new information. The rate of progress of information use is usually governed by how quickly hypotheses can be tested, how many replicates can be formed, how good the controls can be, and whether treatments can be randomized. Unfortunately, societal changes in leadership, management, and political appointments do not occur on the time scales required for management or understanding of natural systems. The supposition that planners are willing to wait patiently for answers that may take decades to determine runs against the grain of politics (Volkmann and McConnaha, 1993). This raises concern over what institutional arrangements are served, and what gains can be clearly identified, by implementing one strategy over another.

Scientists are often reluctant to engage in political or policy-related matters, other than through the academic media. Many scientists fear that involvement in such processes might compromise their research goals, and may eventually even dilute the scientific integrity of their work. As a result, valuable scientific insights, so important to each stage of species monitoring and ecological recovery programs, are often lost at the point where they are most critically needed, and least understood. An unintended consequence is:

• that complaints by scientists related to the mis-use of science, lack of attention to the appropriate data and interpretations, misconception of information, or funding judgments, lose legitimacy.

We are still faced with the twin problems of management's tendency to avoid useful scientific information that is already available, and scientists tendency to produce information that is dismissed as not having addressed management questions. Some major concerns expressed during the Integration Working Group discussions at Fern Mountain included: the presently-uncertain situation of future Colorado River research emphasis; the need to develop better methods of communicating uncertainty to decision makers in order to reduce its detrimental impacts; and the need and desire to interact more effectively with other disciplines involved in the policy process.

Several process-based questions were raised by the group as impediments to practical AM implementation (see also Pulwarty and Redmond, 1995). These included:

• What are the roles and issues of concern of the stakeholders (Tribes, power interests, etc.)?

• How is scientific information misconstrued by non-scientists, and how is learning presently achieved?

• How, and in what forum, does the will to implement experiments evolve once scientific consensus has been reached, such as in the case of the decision to implement the proposed 1996 experimental high flow?

• How long do experiments have to be carried out before their benefits are realized, or appropriate lessons identified and incorporated into AM?

Dam operations alone cannot meet some objectives for endangered fish over the long term, or be expected to mitigate catastrophic events controlled mainly by natural forces. As such, it may be necessary to repeat the call to establish a second population of humpback chub in the Grand Canyon, as specified in the Biological Opinion (U.S. Fish and Wildlife Service, 1994). Over the short-term, success means making significant measurable progress towards maintaining viable populations, representing suitable habitat types, etc. If AM is an ongoing experiment, then what is its role in ecosystem management and restoration; how do we ascertain when ecological integrity has been protected (Grumbine, 1994)?

Managers must communicate their objectives, including needs and priorities, to scientists so that questions relevant to decisions making are addressed effectively. Primarily, information on measures needed to evaluate and judge scientifically-based strategies for AM experiments, in a cost-effective and timely manner, would be useful. Managers must be able to get a clear picture of how recommendations being considered conflict with each other. It is important to note that AM does not take decisions out of the political arena or escape unscientific pressures. A great concern exists with scientists, in that some managers may lend too much credence to a model when they may not fully understand its limitations. This being said, previous AM strategies, for instance, in the Pacific Northwest, are beginning to result in increasing sophistication in dealing with computer modeling, (e.g., seeing models less as a means of prediction and more as logical ways to compare management alternatives and their uncertainties).

Because management activities often impose major perturbations on the environment, they can also function as experimental investigations of ecosystem functioning. In general, however, the EIS preparation process, and development of other documents on the effects of proposed actions on the environment (environmental assessments or EAs), are often seen as an effort to satisfy legal rather than scientific requirements (Orians, 1986; Naiman and others, 1995). Rarely if ever, is there explicit recognition that natural-system experiments are, by necessity, carried out at scales outside of conventional scientific endeavors. Admittedly, the combined environmental legislation of the last three decades has not provided all the solutions required to maintain biodiversity or ecosystem preservation (Naiman and others, 1995).

In AM, an effort is made to illustrate how case-specific ecological knowledge, rather than general ecological theory, might be used in environmental problem solving (see Orians and others, 1986). The AM process appears to offer great promise for long-term success in managing resources in the Lower Colorado River, but will not be accomplished without overcoming some significant institutional challenges. At the same time, AM also offers many opportunities for highly-conspicuous experimental failures, as will any endeavor faced with significant degrees of uncertainty. The AM program's success should therefore be redefined in terms of useful information gathered, and the appropriateness of the design of experiments, rather than the absolute correctness of predictions (Holling, 1978; Orians, 1986). This last consideration may turn out to be the most formidable barrier to successfully implementing AM at GCD, or anywhere else.

The Role of Science and Scientists in Adaptive Management

AM is ecosystemic rather than jurisdictional, and its time scale is that of biological generation. Much has been said about the need for long-term monitoring and research, but less about the foundations needed for a scientifically-based long-term management plan. Too often, monitoring is perceived as a system of measures to detect divergence in the abundance or condition of a resource from some baseline value. In the case of the humpback chub's typical lifespan (20-30 years or longer), the baseline values may very well be arbitrary. Often, responses are too short-term, and aimed at resource issues relative to the standing political climate of a given administration, rather than to the broader meaning of change in terms of an ecosystem's total response, or in step with what adjustments in management may be needed to ensure ecosystem survival. Presently, legislation continues to mandate single species preservation, while habitats continue to change and become degraded, fragmented, or both. In addition, the integration of long-term data bases to be collected in Grand Canyon, and information from ongoing river research on disparate parts of the ecosystem, have received too little attention. At present, there is a lack of synthesis among scientists on how data bases can or should be integrated, even once strategies of large-scale analyses are agreed upon. This is particularly true in regard to the technical differences (e.g., levels of detection, quality control, archival needs, different scales needed, use of pre-existing data) involved in each sub-discipline.

To avoid conflicts between the temporal and spatial scales of human decision making, and time scales of environmental variation (i.e., to create a situation in which AM approaches can actually be implemented and learned from), it is evident that mechanisms for developing 'usable' information from experiments need to be devised. Usability, here, also implies a clear comparison between desired objectives and actual capabilities of researchers. The Fern Mountain integration meeting in August, 1995, was designed as a first step in this direction. AM, by definition, involves refinement of the data and analyses on which scenarios are developed. Two key areas in which GCES scientists working on endangered species can make contributions to the AM process are: (a) integration of environmentally diverse data bases; and (b) risk assessment and communication.

(a) Data Integration

Communicating information requires a careful review of data-base integrity, levels of possible interpretation, and hardware limitations potentially faced by integration scientists. This assessment is required to overcome likely interface problems by the disciplines involved in life history and population viability assessments (National Academy of Sciences, 1995). If carried out by cooperating scientists, such assessments can result in a series of useful case studies that produce significant new knowledge, and promote valuable interdisciplinary relationships and interactions among scientists. Additional progress needs to be made in regard to identification and evaluation of criteria for what shall be monitored, methods for communicating results of integrated data analyses that are relevant to the life history and survivability of endangered species, and overall models of how resources are related to GCD operations.

Key issues to be addressed should include (see also National Academy of Sciences, 1995):

- Definition of user and user groups at each step of the data path (data collection to analysis)?

- How will the diverse user needs be accommodated, and how will these needs be identified?

- Determining whether assessments require the interfacing of disparate databases, and is the need for this process understood or recognized?

- Initiating pilot studies that are designed to assess data integration issues and solutions on local to-regional scales (see Melis and others, in press);

- Determining how data integration issues can be addressed throughout the life of a project, in light of inevitable political and societal changes;

- Identifying provisions for developing and making metadata available to scientists and managers, and for the presentation of such data, their costs (as in GIS format)?

- Identifying agencies or groups responsible for scientific data integration;

- Identifying the institutional conditions, existing practices, and existing or potential conflicts that restrict data integration; how these can be addressed?

- Identifying processes that facilitate learning within this setting. Where are statistical control cases set up?

It was clear to all involved during the Fern Mountain meeting (Integration Working Group), that efficient communication linkages needed to be designed and implemented in integration efforts so that management can be involved from the beginning design phases of future research projects. The first opportunity for such planning was recognized by this integration group as being the proposed spring, '96 experimental flood.

(b) Risk Assessment and Communication

While the approach of AM, learning from uncertainty, is quite logical, surprise in a practical setting is perceived as a measure of failure (Lee, 1995). Carrying out one experiment, or testing one hypothesis, in a natural setting usually means that other parameters are disrupted for the sake of new knowledge; under this approach, unforeseen consequences will likely occur. The common alternative method of trial and error, for the most part, allows for only one type of agenda or need to dominate, and for surprises in natural systems to lead to resource degradation. For example, controversy about relationships between river flow and humpback chub survival will not likely be resolved by conducting experiments that focus exclusively on sediment issues. Carefully controlled studies may not mimic natural situations, such as sand bar rejuvenation. Indeed, the planned high flow in spring, 1996, may produce unknown effects, including: impacts on the sediment-depleted reach from Glen Canyon Dam to the Paria River, reduced availability of sand in Marble Canyon for delivery to eddies during future high flows, varied flood responses to opening and regenerating return-current channels and backwaters, unknown losses of wetland and riparian vegetation and associated habitat used by endangered species, the immediate displacement of endangered species and degradation of their habitats, and degradation of riverside cultural resources (Patten, 1994).

Ultimately, the question is not whether to maintain or increase humpback chub numbers, but how to do so through restoration and preservation of intact habitats. This has far-reaching repercussions for the restoration of the Colorado River System as a whole, if this is actually an agreed upon goal. In AM, information from monitoring is used to continually evaluate and adjust management policies and practices relative to predicted responses and predetermined thresholds of 'acceptable' change (Kessler and others, 1992). The endangered species listings can bring diverse parties closer to the common goal of addressing ecological uncertainties. However, the ESA's legislated aversion to risk leads to a much slower rate of learning for less robust populations. For instance, flow augmentation to prevent lethal levels of water during dry years, reduces the dry to-wet year difference, and narrows the range of conditions that can be monitored. Without a coherent conceptual framework, elements of the program which work at cross purposes may not be readily identified in a timely manner.

In general, managers make a choice among alternative actions in an effort to reach desired social, economic, and biological objectives. Key uncertainties result from estimates of current fish numbers and their potential productivity. For example, the production of a 'single' estimate of fish-population viability should not be the only goal. Since we do not know how many individual fish are necessary to prevent population extinction or what that the extinction probability is, decision tables for hypotheses must be constructed. Decision tables serve to illustrate the consequences of different management alternatives and hypotheses (suggested in the preceding sections), and highlight two critical aspects of uncertainty: population viability; and the risk or expected consequences of decisions implemented. A key component would be to communicate the uncertainty associated with other factors that may influence the outcome or implementation of each experiment (such as climate variability, recovery strategies for other special status species etc.), which can result in surprise.

Usually, decision makers will choose the most optimistic scenario from their point of view. It is critical that estimates of viability not be aggregated to avoid synthesizing contradictory, or divergent information. It is imperative then, that the model builders (conceptual or numerical) develop ability, or have some group or individual who they trust, work and communicate with regarding the diverse makeup of decision making bodies. AM groups should keep and utilize consistent integrated databases with the same formats over time, and require that scientists present information to the AM Work Group and Annual Operating Planning Group, with suggestions for arriving at coherent views of uncertainty. These uncertainty assessments should be carried out as frequently as new information allows.

Getting Started

To incorporate the natural, cultural, and economic factors that must be ingrained into AM strategies requires a balanced and careful review of current knowledge, and frequent assessment of the problem definitions, issue frames, and constraints under which the different stakeholders operate (incompatibility of agency missions, etc.), within a comprehensive management-planning framework. Key questions to be addressed under this framework include:

- What are the major goals and priority issues?

- To whom are they important, on what time scales, and why?

- What trends and thresholds affect (and limit) the realization of these goals (including long-term monitoring requirements)?

- Where did these priority issues originate, and will they persist?

- What factors are influencing the presently observed trends?

- At what rates are driving or influencing factors changing?

- What is the probable course of future events and developments (i.e., projections of viability)? and,

- How can this information be used to change that course, and to realize to accomplish more of the desired goals and management objectives?

It must be emphasized that managers need to prioritize issues and questions to help focus on the most critical information needs in order for researchers to respond appropriately.

It was felt, by the Integration Working Group participants, that managers or staff members needed to be involved in the scientific process, and scientists involved in the management process. This usually necessitates:

(1) an on-going process of involvement within set boundaries;

(2) development of trust and credibility within the forums where interactions occur;

(3) understanding and utilizing tools for communication, including the use of professional moderators to assist in the process;

(4) openly and explicitly addressing uncertainties in literature; and

(5) becoming cognizant of the mismatch of institutional time scales with species life-histories.

Table 1, outlines the institutional situations favoring AM (Lee, 1993). A careful assessment of the extent to which each of these conditions are met in the present management of the Glen Canyon Dam and the Lower Colorado River is necessary for the adoption of any viable AM program. Lessons from the Columbia River Basin experience indicate that, unless these and other conditions discussed above are met, an AM program will have limited success, regardless of how clearly scientific management objectives are defined. These conditions highlight the cooperative contexts necessary for coordination among managers, administrators and scientists. Seldom are the high costs of scientific research, human resource needs, or intrinsic difficulties represented in meeting AM requirements accurately estimated.

As a preliminary first step to meeting the requirements of AM, it was suggested that the GCES group produce a clear statement, in relation to endangered-species issues, such as the humpback chub, of:

- What was not known at the beginning of the scientific study period?

- What was learned scientifically in the last 10 years?
[For instance, is it generally agreed upon that humpback chub were in decline (if so, at what rate) prior to the existence of the Glen Canyon Dam? (What are the present age distributions existing populations? To what degree is there certainty about the role of non-native predators of humpback chub?]

- What questions haven't and (or) cannot be addressed under present scientific constraints?

- What degree of accuracy is necessary from scientific research?

- What are the conditions that prevent scientists from addressing these issues?

- What are the implications and costs of not taking these steps?

- What needs to be done to estimate the probability of persistence of a population at different times in the future, and what are the costs of these efforts?

This document should be presented to, and be read by AM Work Group decision makers, and the interested public.

Traditionally, action is based on existing knowledge and established modes of operation. Information is not sought after strategically, and is often gathered from a narrow range of conditions. AM implies an active search for key hypotheses and a commitment to test them. Policy-makers are more likely to seek scientific advice if scientists are explicitly addressing controversies in the scientific literature, attempting to clarify their implications, and producing coherent assessments useful to decision makers (Pulwarty and Redmond, 1995).

A primary focus for the future is to increase the role of the scientific community in providing ongoing insight into policy decisions and implementation (see Likens, 1992). AM needs to be driven by research that has consequences, if it is to be worth the high costs of ongoing research. It is unrealistic to expect the anticipation and avoidance of all conflicts (Lee, 1993). It is a requirement that the AM group consists of members skilled in management, science, and negotiation. The aim of AM is for decision makers to acknowledge and understand scientific uncertainty, and to act on reasonable hypotheses. The creation and support of interactions between the members of the Technical Work Group, independent program reviewers, and ad-hoc integration groups, like this one, should act to centralize scientific thought, and provide a vital component to AM in Grand Canyon.

Table 1: Institutional Conditions Favoring Adaptive Management

There is a mandate to take action in the face of uncertainty
Decision makers are aware that they are experimenting
Decision makers care about improving outcomes over biological time scales
Preservation of pristine environments is no longer an option, and human intervention cannot produce outcomes predictably
Resources are sufficient to measure ecosystem-scale behavior
Theory, models, and field methods are available to estimate and infer ecosystem-scale behavior
Hypotheses can be formulated
Organizational culture encourages learning from experience
There is stability to measure long-term outcomes; institutional patience is essential
What should managers address? [Important to clearly identify the limits of science and scientists in addressing 'value' issues]

SUMMARY

This prospectus summarized core topics relating to scientific integration that were developed by an ad-hoc group of scientists interested in understanding and preserving resources of the Colorado River. These four main topics were discussed by the group with the intention of suggesting some approaches for integrating existing data, and obtaining future data that would help BuRec evaluate the operation of GCD relative to Biological Opinion issues.

Development of this prospectus was conducted through the Glen Canyon Environmental Studies as part of a larger-scale integration effort to synthesize all known information about Colorado River resources through Grand Canyon. Development of integration approaches to better understand the river ecosystem below GCD is recommended in the Operation of GCD final environmental impact statement. Efforts at synthesis of existing data have been repeatedly suggested by reviewers of GCES, as a means of providing better information to resource managers and decision makers. Unfortunately, owing to many complex reasons, very little integration has been accomplished to date. One of the intended goals of this prospectus was to suggest ways in which former patterns of scientific research on the Colorado River could be modified; mainly through integration of existing information, and design of future interdisciplinary studies. This document represents a process of change, one in which some Grand Canyon scientists have been willing to take more proactive roles in finding new ways of learning about the Colorado River, and then communicating new knowledge to resource managers.

The core topics identified during this highly-interactive prospectus development process were (1) physical-habitat relations, (2) trophic dynamics, (3) population ecology of humpback chub, and (4) adaptive management and the role of science and scientists. Research questions, hypotheses, management implications, and data availability were identified for each core topic, and general approaches to integration of scientific data suggested.

Integrated studies on the significance of physical-habitat may provide managers with more useful perspectives on relationships between geomorphology, and endangered species ecology below GCD. Specific areas of interest include the role of backwater habitat in survival and recruitment of subadult native and non-native fishes, turbidity cover as a form of predator evasion by fishes, localized impacts on abiotic and biotic resources of the river caused by altered river morphology resulting from tributary processes (e.g., debris flows), and life strategies of humpback chub as they may be related to recirculating eddy complexes (use by adults), and shoreline-type distributions (use by subadults).

In addition to river regulation impacts, climate variability was identified as likely being a significant forcing mechanism for changes in habitat; climatic influences probably impact the river's ecosystem in many subtle, but important ways. Climate variability affects both the regulated and unregulated reaches of the Colorado River, as well as its regulated and unregulated tributaries. Climate's impact on river resources has been little studied below GCD, but the possible ecosystem linkages related to hydrology, geomorphology, and aquatic resources warrants further scientific investigation. During recent discussions, integration scientists recognized the possibility that endemic species below GCD are unique, and have probably adopted highly-refined life history strategies that allow them to survive in the Colorado River, despite harsh environmental stresses linked to highly-varied climatic conditions.

The endangered species most directly affected by changes in physical habitat include humpback chub (Gila cypha), razorback sucker (Xyrauchen texanus), southwestern willow flycatcher (Empidonax trailii extimus), and Kanab ambersnail (Oxyloma haydeni kanabensis), as well as the peregrine falcon (Falco peregrinus) and bald eagle (Haliaeetus leucocephalus). Existing dam operations or proposed changes under the Preferred Alternative of the final EIS on the operation of GCD, will likely affect river geomorphology and the habitats of these species. Climatic conditions will also likely result in continual changes in habitats, and these changes may presently be accelerating because of global changes, such as atmospheric warming. However, the significance of physical habitat alteration on the long-term survival of endangered species, whether caused by regulation or nature's climate, remains unclear.

The area of trophic dynamics was described in terms of needs for synthesizing information on the food base and productivity of the river's ecosystem. A critical need to determine the effects of dam operations on primary and secondary production, and to determine the importance of food web interactions on fish population dynamics was discussed and outlined in that section. Future management of this highly "bottom-up" ecosystem will require comprehensive interdisciplinary efforts, both in terms of monitoring and experimentation, if biodiversity is to be preserved and enhanced through use of habitat maintenance flows, or other operational changes at GCD. The role of floods in maintaining the health of the aquatic food web, can be better understood through system-wide experiments, such as the proposed spring, 1996, high flow, but only if such experimental research is conducted in a comprehensive and integrated manner.

The population ecology of humpback chub section dealt with life-history strategies and species interactions of what has become the most studied endangered native fish below GCD. Approaches for developing a conceptual population model were proposed in that section, including needs for identifying existing and missing data, collection of future data for use in addressing specific questions, and for predicting effects of dam operations on fish-population demographics, as well as responses by other species. Many aspects of chub life history are still poorly known, including physical habitat requirements and use in the pre- versus post-dam river ecosystem.

Most GCD Biological Opinion issues relate directly to preservation of viable, existing humpback chub populations, or to establishment of additional populations of these and other endangered fishes. A comprehensive understanding of chub life history strategies, and species interactions is required if preservation objectives are to be met through modified dam operations, as guided by adaptive management. Changes in the thermal characteristics of the Lower Colorado River, resulting from implementation of proposed selective withdrawal structures at GCD, will have consequences for the entire ecosystem. Such changes will need to be anticipated and compared with identified ecologic parameters of endangered species, such as humpback chub, if adaptive management strategies are to be effective.

Adaptive management is identified in the operation of GCD final EIS, as the process of gathering scientific information for management decision making focused on modifying dam operations. The proposed modifications should act to preserve, restore, and protect downstream resources. A clear and effective means of communicating integrated scientific information to decision makers is required for adaptive management to succeed. The final section of this prospective examined the important role that science and scientists must play in successfully implementing adaptive management in the Lower Colorado River.

Management objectives can be met through comprehensive use of integrated scientific data, and through development of solid working relationship between scientists, managers, and other interested parties throughout the Colorado River Basin. The final section of this prospectus, on the role of science and scientists in the adaptive management process, was also intended as a position statement on how science should be ideally used to bolster adaptive management procedures; it was intentionally written from the scientists perspective. Finally, this prospectus symbolizes a cooperative spirit and common interest in better understanding the Colorado River ecosystem, an attitude shared by all scientists that participated in its development. It will also serve as another way to solicit new ideas from, and interactions with, other interested scientists and managers not already involved in integration. Those who are interested in participating in the integration process are welcomed to begin sharing their own views and research experiences gained from conducting freshwater ecosystem research and management.

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IN REPLY REFER TO:

November 10, 1995

MEMORANDUM

To: Ad-Hoc Interdisciplinary Integration Work Group

From: Dave Wegner

Subject: Transmittal of DRAFT Prospectus Integration Report

Enclosed is your copy of the report entitled A Draft Prospectus on Integration of Biological and Physical Data Below Glen Canyon Dam, Arizona: Suggested Approaches for Assessing Biological Opinion Issues. This report represents the combined efforts of many interested scientists who participated in the August 10-11, 1995 Integration Workshop held at Hart Prairie Preserve. Ted Melis took the lead in pulling this document together with the primary authors and deserves the majority of the credit for the final results.

Now you are wondering what is next. Our intent is to use the initiative started at Hart Prairie as a template for the Glen Canyon Environmental Studies Transition Monitoring program and also for the implementation of the controlled Glen Canyon Dam flood, scheduled for late March 1996. Many of the issues and pearls of wisdom identified in the report will be used to help guide this office in implementing an effective process. If we do this right the concept of Adaptive Management will finally have some specific examples.

Once again, thank you for your efforts and we hope we can count on you for future interactions as we move forward with this important effort in the Colorado River.

enclosure

Dave Wegner