REPORT

of a

PEER REVIEW PANEL

on

TERRESTRIAL ASPECTS

of the

BIOLOGICAL RESOURCES PROGRAM

of

THE GRAND CANYON

MONITORING and RESEARCH CENTER

Submitted by this Panel:

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on June 23, 2000

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EXECUTIVE SUMMARY

The Grand Canyon Monitoring and Research Center (referred to here as the "Center") conducts research and monitoring to support an evaluation of the effects of the operation of Glen Canyon Dam on the Colorado River corridor between the dam and Lake Mead. Its Biological Resources Program focuses on both aquatic and terrestrial resources. This report concerns terrestrial resources. A scientific review panel was convened and charged with evaluating the terrestrial biology program. The panel participated in a 10-day raft trip down the Colorado River from Lees Ferry to the Diamond Creek takeout (March 5 - 15, 2000). This trip provided an excellent opportunity for the panel to interact with current and past researchers who accompanied panel members for all or suitable parts of the trip. The panel feels this trip provided an outstanding venue for conducting its fact finding and deliberations. Below is a summary of the panel's major findings and recommendations.

Major Finding and Recommendation

♦ *The Center Has No Comprehensive Terrestrial Monitoring Strategy.*

The Center's terrestrial monitoring program has evolved from predecessor studies. The Center has a series of isolated studies focused on short-term responses at specific sites, and lacks a comprehensive terrestrial monitoring strategy. The result is that ***the Center's current activities are insufficient to detect the dam's effect on the terrestrial ecosystem and its associated species along the main-stem corridor***[1]. The program as currently executed could overlook important effects and also wrongly fault dam operations with biotic changes resulting from natural or exogenous factors (e.g., invasive species or global warming).

> **RECOMMENDATION:** Develop a comprehensive monitoring strategy for addressing the terrestrial monitoring program's diverse mission, rather than the current approach which treats these needs in a piecemeal fashion. This strategy should include the following: a set of generalized, cross-species monitoring objectives based on the Adaptive Management Work Group's specific information needs; a comprehensive, integrated monitoring design for meeting these objectives, which explicitly defines target populations and assures spatial and taxonomic representativeness; and an implementation plan that describes details on the monitoring design, power of detection, indicator selection, sampling protocols (including frequency and scale), data analysis, and data management. The panel recommends a monitoring program that has the following four distinct components:

[1] Interpreted here as the entire Colorado River corridor between Glen Canyon Dam and Lake Mead within the bounds of the old high water zone, perhaps augmented by the lower part of some side canyons. For some purposes – for example, locating and monitoring Peregrine Falcon nesting sites (a stated information need) – this is too restrictive a definition.

- ♦ Endangered species assessments
- ♦ Monitoring for model development
- ♦ Inventory of plants and animals
- ♦ Long-term monitoring of the main-stem corridor

Specific Findings and Recommendations

1. *There Appears to Be Little Scientific Direction to the Monitoring Program.*

RECOMMENDATION: Appoint the Scientific Advisory Board as described in the Long-Range Strategic Plan. The Center also should employ a chief scientist. Both of these suggestions have been made before, most recently by the National Research Council.

2. *There Appears to Be Little Integration Across Disciplines.*

RECOMMENDATION: Encourage cooperation, including shared sampling sites and joint river trips, among investigations of hydrology, sediment transport, fisheries, vegetation, and terrestrial animals. Include specific requirements for such cooperation in RFP's.

3. *There Appears to Be No Mechanism to Ensure Long-term Comparability of Monitoring Data Across Contractors and Center Personnel.*

RECOMMENDATION: Develop protocols for evaluating responses and selecting study sites before any further proposals for terrestrial studies are requested, and ensure that new contractors are properly trained in these protocols.

4. *The Center Has Focused on Short-term Events, Rather than Long-term Responses.*

RECOMMENDATION: Have the Adaptive Management Work Group and its Technical Work Group incorporate a long-term perspective into their information needs. This perspective should also be incorporated into monitoring plans and methodologies.

5. *Insufficient Emphasis Has Been Placed on Developing Models That Will Predict the Effect of Dam Operations on Terrestrial Ecosystems.*

RECOMMENDATION: Develop a terrestrial ecosystem model with the same level of detail as the current aquatic model. Such a model, linked with field work on specific ecological relationships and ecosystem responses, is probably the only way to address "what if" management questions regarding dam operations.

6. *The Effort Dedicated to the Kanab Ambersnail Is out of Proportion Compared with Work on Other Field Components.*

RECOMMENDATION: Confirm whether or not the snail population at Vasey's Paradise is actually the Kanab Ambersnail. Reduce the scale and frequency of the current monitoring effort and use minimally invasive methods. Minimize disruption of other endemic snail species caused by translocation of the Vasey's Paradise population.

7. *The Center Has Several Immediate Needs Before a Monitoring Program Can Be Implemented.*

RECOMMENDATION: The Biological Resources Program, in collaboration with other programs of the Center, should place high priority on developing and/or completing a number of products needed for development of a comprehensive monitoring program; e.g., a Geographic Information System coverage and current land cover map of the entire river corridor, a random sample of spatially distributed study sites, cost effective response indicators and protocols, and protocols to ensure inter-disciplinary cooperation.

1 - INTRODUCTION

The Grand Canyon of the Colorado River is a geological and ecological wonder of the United States. It has been inhabited and affected by flora and fauna for many millennia. Most recently, the river and nearby areas have been impacted in a number of ways by the Glen Canyon Dam. Prior to the dam's closure in 1963, snowmelt-fed runoff scoured off most vegetation near the river. These flows carried substantial amounts of sediment into and through the canyon, which allowed sand bars to be rebuilt almost annually. Desert temperatures gradually warmed the river's water throughout its course, a process well underway before the river reached Glen Canyon.

The impoundment of flow in Lake Powell by the Glen Canyon Dam has caused these features to change. The water leaving Lake Powell carries virtually no sediment, is quite cold (~ 8°C), and flows have been substantially moderated compared to the pre-dam period. The cold, clear water has led to an outstanding sport fishery developing immediately below Glen Canyon Dam, and perhaps has endangered several native fishes such as the humpback chub. The disappearance of the nearly annual scouring flows has allowed the emergence of a thriving near-river riparian community, and a dramatic increase in the size and diversity of bird populations. Reduced sediment input and reduced sediment transport to sand bars has led to a gradual erosion of sand bars. During this same time recreational rafting has increased greatly. Rafting has probably benefited from the moderation of flows, but may be negatively impacted by the disappearance of sand bar areas used for camping and by encroachment of vegetation into the remaining areas.

Native Americans have had a presence in the Grand Canyon and the surrounding countryside for several millennia. The remains of Anasazi dwellings and granaries attest to that in the more recent past. Various tribes attach food, mineral, cultural and religious significance to sites in the Grand Canyon. Operation of Glen Canyon Dam also can impact such current and past sites, but these impacts lay outside of the scope of this report.

Clearly the impoundment of water behind Glen Canyon Dam and its subsequent release under regulated conditions has altered the river and the near-river areas as well as associated flora and fauna. Whether these changes are good, bad, or neutral depends tremendously on the values of the person or organization evaluating them.

The Grand Canyon Monitoring and Research Center (GCMRC, referred to here also as the "Center"), now a unit of the Geologic Survey, U.S. Department of the Interior, is charged with monitoring and conducting research on the Colorado River corridor in the Glen and Grand Canyons to evaluate the effects of water releases from Glen Canyon Dam. The Center convened a peer-review panel to evaluate its monitoring and research on vegetation in the area close to the Colorado River, specifically in the area below the "old high water line." The panel was composed of:

N. Scott Urquhart, Chair, Statistics, Monitoring Design and Analysis
Gregor T. Auble, Riparian Ecology
John G. Blake, Avian Ecology and Community Ecology

Douglas T. Bolger, Conservation Biology, Landscape Ecology, Birds
Timothy Gerrodette, Monitoring Design
Scott G. Leibowitz, Wetland and Landscape Ecology
David C. Lightfoot, Desert Ecology, Entomology
Alan H. Taylor, Geography, Plant Ecology, Landscape Ecology

The panel reporting here was initially approached to consider vegetation, but the panel's composition made it clear it needed to consider the entire terrestrial ecosystem. The panel's convener, Barbara Ralston, Acting Director of the Biological Resources Program, GCMRC, concurred with this conclusion.

This panel carried out its review in an unusual, if not unique, venue: a 10-day raft trip through Grand Canyon from Lees Ferry (river mile 0) through the Diamond Creek takeout (river mile 225). The panel also had an opportunity to hike from Tapeats Creek (mi. 134) to Deer Creek (mi. 136). The panel feels this trip was critical to its understanding of the Center's current and past monitoring and research, and to the challenges of conducting scientific work in the Grand Canyon. The panel profited from discussions on the river and at monitoring/research sites throughout the trip with Lawrence Stevens, Matt Kaplinski, John Spence, and Barbara Ralston. Michael Kearsley, Jeff Sorenson, Josh Korman, and Matt Johnson discussed their research activities from Lees Ferry to Phantom Ranch. Linda Jalbert joined the trip from Tanner Camp to Phantom Ranch to relate perspectives of the National Park Service. Mike Yeatts joined the panel at Phantom Ranch and provided an ethnobotanical perspective. The panel would especially like to thank and acknowledge the river guides – Jeff Behan, Carol Fritzinger, Matt Kaplinski, Michael Kearsley, Lynn Roeder, John Running, and Lawrence Stevens – for taking care of all the details and providing us with a wonderful experience, and for sharing their vast knowledge and appreciation of the River, its environment, and culture. We also would like to thank James Workman for his stimulating conversations and his insider's perspective. Finally, we would like to acknowledge Loretta Jackson and Art Phillips, who briefed us before the trip on the ethnobotanical interests of the Hualapai tribe.

The panel represented a very diverse set of professional perspectives, yet reached complete consensus on all of its major findings and recommendations. An overview of the panel's findings and recommendations appears in the Executive Summary. The major finding and recommendation, along with a proposed monitoring framework, is given in Chapter 2. Chapter 3 describes seven specific findings and recommendations. Responses to specific questions posed to the panel follow in Chapter 4. Several panel members wrote about specific points in their area of expertise; those follow in Appendix A. Other appendices list the panel's activities on the river, materials considered by the panel, and give biographical sketches of the panel members.

Although the panel was drawn from a number of government agencies and universities, the recommendations of this panel are solely the opinions of these eight individual scientists, and should not be construed as representing the positions, judgments, or policies of their respective agencies or universities.

2 - A PROPOSED MONITORING FRAMEWORK

2.1 The Center Has No Comprehensive Terrestrial Monitoring Strategy.

The Center's terrestrial monitoring program has evolved from predecessor studies. The Center has a series of independent and unlinked studies focused on short-term responses of specific sites, and lacks a comprehensive terrestrial monitoring strategy. The result is that ***the Center's current activities are insufficient to detect the dam's effects on the terrestrial ecosystem and its associated species along the main-stem corridor***[2]. In fairness to past projects and researchers, the panel acknowledges that quite a lot has been learned about the corridor ecosystem and its response to dam operations. Nevertheless, the program as currently executed could overlook important effects and also wrongly fault dam operations with biotic changes that result from natural or exogenous factors (e.g., invasive species, recreational impacts, or global warming).

As this report expresses substantial reservations about the monitoring activities of the Center, it is important to first define what we mean by monitoring. The Oxford Dictionary (1995) defines monitor as a verb which means "to maintain regular surveillance over (something of interest)." The U.S. Environmental Protection Agency (EPA) defines it as "periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media [air, soil, water] or in humans, plants or animals" (EPA 1992). EPA's Environmental Monitoring and Assessment Program (EMAP), which is concerned with ecosystem condition, gives monitoring a more specific definition (EMAP 1993): "the periodic collection of data that is used to determine the condition of ecological resources."

The definition advanced by EMAP meets the Center's need because it focuses on ecological resources, as the Center is tasked to do. For purposes here, the "ecological resources" in the EMAP definition would be the terrestrial ecosystem between Glen Canyon Dam and Lake Mead up to the Old High Water Line, and possibly expanded for specific purposes. The "periodic" in the EMAP definition means the resource should be revisited on a planned schedule. This might be as frequent as several times a year or as infrequent as once every few years, but it would adhere to a planned schedule. The sampling should be made at sites which allow inference to the entire ecosystem (the population in a statistical sense). This means the plan for site selection has to have some probability or sampling components to support inference to the entire resource. Purposefully picked sites limit inference to those sites; probability selection allows inference to the whole resource. The EMAP definition leaves open the question of what responses to evaluate, but acknowledges the importance of the choice of responses with the phrase "condition of the ecological resource." However, the monitoring should be taxonomically representative, and not just focus on a limited number of

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[2]Interpreted here as the entire Colorado River corridor between Glen Canyon Dam and Lake Mead within the bounds of the Old High Water Zone, perhaps augmented by the lower part of some side canyons. For some purposes – for example, locating and monitoring Peregrine Falcon nesting sites (a stated information need) – this is too restrictive a definition.

species.

Current monitoring efforts are not spatially representative and do not sample all ecosystem components. Recent Center activities have focused almost exclusively on beach-eddy complexes, and have ignored river margin areas. The panel was led to believe that there is no reliable estimate of the total area of river margin sediment deposits at any flow level. Given their nearly continuous presence throughout the corridor, river margin habitat may actually constitute more riparian area than the eddy-bar complexes. Clearly the eddy-bar complexes are of great interest to the recreation industry and provide habitat for many birds, yet an almost exclusive focus on them may neglect an important component of the corridor ecosystem. For example, beavers apparently live in burrows in river-margin bars. Another important omission is the lack of any information on side canyons and streams. It is already understood that side streams are now the major source of sediment into the mainstem river, because of upstream sediment trapping by the Glen Canyon Dam (Chapter 1). Biological interactions between the mainstem river and side channels may also be important, but have not been investigated; e.g., the role of side streams as spawning grounds for native fish, the role of side canyons as refugia, and the role of side canyons as sources of exotic species. Taking a broader view of the river corridor that includes a landscape perspective could be important in understanding the ultimate impact of dam operations and in differentiating the effect of dam operations from other factors. The need for information on the whole river corridor, including river margins, is also an example of why a current vegetation map of the entire corridor is critical (see Section 3.7.2).

Similarly, monitoring efforts are not taxonomically representative. As far as the panel is aware the Center's recent terrestrial activities have involved principally riparian plants and birds, with some focused work on what has been thought to be the Kanab Ambersnail (possibly misidentified as *Oxyloma haydeni kanabensis*) and the Southwestern Willow Flycatcher. A result of this piecemeal focus on a few particular species is that other important species have largely been ignored. For example, beavers are currently not being monitored. Conversations with trip members with long experience in the corridor suggest beaver was fairly uncommon pre-dam and shortly thereafter. There appears to now be a thriving population, perhaps an excess, of beavers. It appears they have virtually eliminated the Goodding willow in the corridor, and frequently dig up river-side vegetation in their search for roots to feed on.

Finally, no written document apparently exists specifying terrestrial monitoring objectives or detailed sampling design and procedures. It is therefore difficult to determine whether current activities are meeting specific monitoring objectives. The panel is also unaware of a conceptual model or set of hypotheses concerning terrestrial ecosystem dynamics which could serve as a framework to guide research monitoring efforts. Such a framework would facilitate progress and help set priorities.

2.2 The Center Should Develop a Comprehensive Terrestrial Monitoring Strategy.

RECOMMENDATION: Develop a comprehensive monitoring strategy for addressing the terrestrial monitoring program's diverse mission, rather than the current approach which treats these needs in a piecemeal fashion. This strategy should include the following: a set of generalized, cross-species monitoring objectives based on the Adaptive Management Work Group's specific information needs; a comprehensive, integrated monitoring design for meeting these objectives, which explicitly defines target populations and assures spatial and taxonomic representativeness; and an implementation plan that describes details on the monitoring design, power of detection, indicator selection, sampling protocols (including frequency and scale), data analysis, and data management. The panel recommends a monitoring program that has the following four distinct components:

- ♦ Endangered species assessments
- ♦ Monitoring for model development
- ♦ Inventory of plants and animals
- ♦ Long-term monitoring of the entire main-stem corridor for condition and trends

Each of these four tiers is designed to address different management needs. Thus each tier has different research objectives and requires its own monitoring design. Below we describe the type of information each tier is meant to provide, specific research objectives, and discuss the interconnections between tiers. This is then followed by sections outlining a proposed sampling design for the last three components. Finally, we also discuss the need for a detailed implementation plan.

2.2.1 A Four-Tiered Perspective

Endangered species assessments: The first component of the proposed framework is the existing work on the corridor's two endangered terrestrial species, the Kanab Ambersnail and the Southwestern Willow Flycatcher. This work is narrow in focus with regard to biological and legal/programmatic needs, and its objectives and designs are well established. Thus we only touch on this tier briefly. Specific recommendations for the ongoing bird research are given in Appendix A.2. Also, this panel believes that the question of whether the Vasey's Paradise snail is actually the Kanab Ambersnail needs to be resolved (Section 3.6), given that the current level of monitoring takes scarce resources from other field efforts, and because attempts to establish the snail at new sites could be harming other endemic snail populations. Until the genetics of this snail are resolved, it should be monitored with minimally invasive methods. Because the monitoring for endangered species is so specific and constrained, this panel has no further comments about this tier in this chapter.

Monitoring for model development is specifically designed to address "what if " management questions regarding dam operations. For example, what are the effects of altered flow regimes or water temperature on bird community structure. This work is meant to describe, validate, and quantify relationships between identified response variables and functionally related independent variables. For example, bird abundance could be related to the vegetation community, which in turn is related to sand grain size and beach elevation, which is ultimately related to the River's hydrology. Knowing these relationships, the effects of a given flow regime on bird abundance could be predicted.

A plant and animal inventory of the entire main-stem corridor would provide scientists and managers with a complete list of species present in the canyon, their spatial distribution, and a basis for evaluating changes in species occurrence over time. Such an inventory, at least in an abbreviated form, needs to be repeated periodically. The inventory can inform researchers of populations that may require further study, alert managers to new invasions, and could indicate loss of species due to dam operations or other factors.

Long-term monitoring of the entire main-stem corridor allows long-term trends to be described. This information would determine the spatial and temporal variability of various resources and allow the canyon to be described as a whole ecological unit. This information is critical in assessing whether an observed change is due to dam operations or within the range of natural variability. In addition, the combination of whole-corridor and model-based information allows for inferences to be made for the canyon as a whole. For example, given the relations between birds and terrestrial biota from the model-based work, and knowing the entire corridor distribution of vegetation, inferences could be made on the bird populations in the entire corridor.

2.2.2 Monitoring for Model Development

Like any biological system, the terrestrial ecosystem of the Grand Canyon exhibits natural variation, and also can change in response to factors such as global warming, invasive species, or recreational use. It is therefore not a simple matter to separate the effect of dam operations from these other factors. To do so properly would require an experimental approach where the short- and long-term effects of a single management action (such as operating the dam according to a given flow regime) could be compared with controlled conditions. Sites up-river from Lake Powell or in side canyons to Marble and Grand Canyons might be considered for controls. However, these locations are in different areas and represent different environments from the mainstem river corridor. Thus no true controls exist for experimental comparisons (although these sites could still serve as ad-hoc pseudocontrols for specific questions).

An alternative approach would be before and after experiments. This would require both pre- and post-treatment flow regimes to be maintained for a period of at least 5-10 years. Such a period of time would be necessary to allow the temporal variation associated with each flow regime to be characterized, and to incorporate factors such as exotic invasions and climate change, and allows the terrestrial biota an opportunity to respond to the flow regime.

Given the realities of dam operations, it is unlikely that either of these approaches to controlled experiments can or will be implemented. Even if implemented, it is not likely that such an approach would be able to discern the long-term effects of moderate (e.g., 45,000 cfs) spike floods on the terrestrial biota. Therefore, we believe that the best approach to assessing the impacts of controlled water releases on the riparian corridor – and to ensure that changes to the ecosystem are not falsely attributed to the dam – is to monitor this system over time, and then use the resulting information to develop hypotheses about functional relationships between dam operations and the distribution and abundance of plants and animals. This monitoring should not be designed around isolated experimental flows, but should instead capitalize on spatial variation in the features of interest. The functional relationships can then be expressed in a model that relates terrestrial responses to dam operations. Small scale experiments and ad-hoc use of pseudocontrols should also be used to help define and validate these relationships.

In particular, we recommend that monitoring and research activities be designed to extend the aquatic model presented by Dr. Josh Korman, of Ecometrics Research, Inc., to include the terrestrial biota. This will require identifying critical relationships between the flora and fauna and components of the hydrograph (e.g., sediment dynamics). The modeling needs to include a generalized approach that focuses on broad biotic groupings; e.g., relating bird abundance and diversity to vegetative diversity. It will also need to include relationships between specific components, in order to address particular Information Needs. For example, the following important relationships could be considered for inclusion:

- The competitive relationship between tamarisk and willow and how this is affected by edaphic and microclimatic variables influenced by water temperature and other hydrograph components.
- The relationship between woody plant community composition (willow/tamarisk), arthropod community composition and bird foraging.
- The influence of beaver on woody plant and grass dynamics.
- The relationship between the abundance of individual bird, reptile and mammal species and woody plant community composition.

The term "model" can be applied to a number of different approaches, from simple statistical models based on empirical relationships to dynamic simulation models that incorporate mechanistic relationships. The specific needs of the model and its operational constraints should dictate which techniques are used. However, one approach might be to start with simpler, empirically-based models that incorporate broad functional relationships, and then add specific relationships and use more complex approaches as required.

2.2.3 Plant and Animal Inventory

A biological inventory survey of the entire main-stem corridor is needed. Biological inventory efforts to date have been too limited in taxonomic, spatial, and/or temporal scope to provide a complete whole-corridor assessment of the flora and fauna. (See Appendix A.3 for more detail on such surveys.) Understanding the taxonomic composition of the flora and fauna is essential to any whole-corridor long-term monitoring program. A base-line biological inventory survey will not only provide documentation of which plant and animal species occur in the canyon, but also provide a foundation for future long-term biological resource monitoring efforts. Water-flow regimes regulated by Glen Canyon Dam are likely to alter species composition and spatial distribution patterns of those species over time in some unanticipated ways. Documentation of which species occur in which environments initially and over time, is necessary to monitor such changes in species composition and distribution patterns along the riparian corridor.

A species inventory should include a series of sites or locations that are randomly distributed throughout all reaches of the riparian corridor. A variable density grid-based sampling design, described in the next section and in Appendix A.4, could be utilized to select a series of sites, emphasizing sites that represent particularly important geomorphic features such as beach-eddy complexes. The total number of sites chosen will depend upon the relationship between statistical power and logistic and financial feasibility. A whole-corridor distribution of inventory sites would provide an initial database that could be used to monitor the geographic distributions of species relative to changes in the physical canyon environments. An inventory survey should also be conducted over a period of years to account for inter-annual variation in climate and related biotic species population fluctuations. Intra-annual sampling would be necessary to account for different seasonal life-history patterns of the various plant and animal species. A whole-corridor inventory survey should range from three to five years, to maximize potential encounters with as many species as possible. With suitable design considerations the inventory could be conducted over several years, conducting the field work at an interspersed subset of sites each year. All taxa should be systematically surveyed at each site, with equal effort across all sites, seasons, and years.

An assessment of plant and animal species associations among the various high-water zones will be necessary to monitor the effects of fluctuating water levels on biotic communities. An inventory survey that incorporates differential sampling of water-level riparian zones will provide information on which species occur at which sites, and how various species are distributed across the riparian water-level gradient. Three water-level zones should be differentiated; 1) the old high water (100,000-300,000+ cfs), 2) the new high water (20,000-100,000 cfs), and 3) the fluctuation zone (<20,000 cfs).

The data obtained from a biological inventory should be linked to existing biological resource data, as well as physical and cultural resource data. All of these data will be more valuable when they can be cross-referenced (e.g., relational database) to data from other disciplines. For example, biological resources respond to changes in physical resources. Biological resources can alter processes affecting physical resources, such as vegetation cover altering beach erosion. Cultural resources tend to be associated with certain physical and biological resources. The most robust biological inventory and monitoring design will overlap physical and cultural resource inventory and monitoring to the greatest extent possible.

Appendix A.3.1 provides an example of a whole-corridor biological inventory that incorporates the concepts discussed above. It illustrates how a whole-corridor biological inventory might be designed. An actual inventory design could be developed from this model, depending upon the specific monitoring goals. This inventory model incorporates existing biological resources data, and would provide biological species inventory data applicable to a wide range of research and monitoring questions. This inventory model could also provide the foundation for a whole-corridor long-term biological resources monitoring program.

2.2.4 Long-Term Monitoring of the Main-Stem Corridor

A carefully planned biological inventory design may be continued over time with slight modifications to provide a sampling design and protocol for whole-corridor long-term (decades) monitoring of biological resources. The advantage to such an approach is that information obtained from the flora and fauna inventory would then provide the baseline species lists, habitat associations, and geographic distributions necessary to assess subsequent changes resulting from variation in water-flow. Target taxa should be selected from the entire list of plant and animal species documented from the inventory. Target taxa for monitoring should have the following taxonomic and ecological characteristics:

- Common, representative species of particular habitats, including both habitat generalists and specialists;
- Taxa that are relatively easy to identify and to collect;
- A range of species representing different taxonomic and trophic groups; and
- Taxa across a range of life-history patterns from short-lived annual species to long-lived perennial species.

Target taxa, representative of different habitats across the three different water-level zones (old high, new high, and fluctuation zone), should be monitored with equal effort at all sites and times. Temporal sampling could be reduced from the inventory effort of four times each year, to just two times each year. A spring (March-May) sample would provide information on annual species of plants and arthropods which are present as mature individuals only during the spring season. An autumn (September-November) sample would provide information on perennial and annual plants and arthropods that occur as adults through the late summer season. Most mid-summer taxa are likely to be encountered during an autumn sample, and most winter taxa are likely to be encountered during a spring sample. Selection of target taxa could focus on those species that best represent the spring and autumn flora and fauna, based on inventory findings.

The actual monitoring design chosen will depend upon the priorities of long-term monitoring goals for biological resources. Which target taxa are chosen will also depend upon specifics of these goals. However, since long-term monitoring objectives and goals will change over time (especially decades), a long-term monitoring design should be simple and flexible enough to provide useful data for unforeseen needs and future goals and objectives. An example model of a long-term monitoring program as a continuation of the initial biological resources inventory survey, is presented in Appendix A.3.2.

The whole-corridor monitoring should be based on a statistically sound sampling plan (site selection), ecological indicators that have been evaluated for cost-effectiveness, and a prudent allocation of effort through time. The panel suggests the Center consider using a randomized grid structure (Appendix A.4) with nested variables of the sort used by the U.S. Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP), and documented by Stevens (1997). Such a set of points are distributed through space with randomization, but point density can be varied by other known attributes of the points in space, and nested subsets of points can be constructed easily. The latter feature allows a randomly selected, but spatially-balanced dense grid of points for inexpensive responses, such as vegetation cover classified by remote sensing, but spatially balanced subsets of points at which more expensive responses also can be evaluated. Existing applications in coastal waters off California have used three levels of variable nesting, and varied site sampling density by ocean depth, geographic areas, and nearness to outfalls from wastewater treatment plants. This application distributes points at the scale of kilometers, but the same methodology has been used at the scale of meters in estuaries. Use of this technology requires a Geographic Information coverage (GIS) of the boundaries of the study area and of any features by which point density is to be varied.

2.2.5 Implementation Plan

Before a long-term monitoring program can begin, a detailed implementation plan should be developed. Current management objectives and information needs constitute desired outcomes of monitoring; they do not define reasoned monitoring objectives. The implementation plan should describe how the proposed activities accomplish these specific monitoring objectives. The plan should be a written guide to provide standardization and continuity to the monitoring program. Development of an implementation plan is a critical task that should begin as soon as possible. However, it is also a task that will require substantial time and effort - probably 1-2 years. Several members of the panel have had sustained involvement in monitoring biological resources. In their view, such a plan should describe: 1) monitoring objectives, 2) details of a sampling design for selecting sites, 3) the size of the effect (and power of detecting that effect) that drove the sampling design, 4) sampling methods and protocols for evaluating responses, including scale and frequency of sampling, 5) analytical methods, and 6) data quality and management.

Given that funding levels have historically been low for the program mission, it is especially important to consider alternative indicators that are cost-effective. Also, not all variables have to be sampled on the same schedule. A draft monitoring plan could include several potential funding levels and, within each funding level, several options for distribution of funds and sampling. For each option, the probability of detecting changes in each monitored variable should be estimated. After external review, the various monitoring options should be presented to the TWG and AMWG for review and approval. Perhaps most important, the development of a monitoring plan should be approached comprehensively, considering all information needs and budgetary or logistical constraints, rather than in a piecemeal fashion.

3 - SPECIFIC FINDINGS AND RECOMMENDATIONS

3.1.1 There Appears to Be Little Scientific Direction to the Monitoring Program.

There has been only modest external scientific input to the Center's terrestrial program. The program that exists seems to be a set of short-term, investigator-driven projects which have evolved from the Glen Canyon Environmental Studies and the studies needed for the Glen Canyon Dam Environmental Impact Statement. A long-term monitoring program will require strong scientific leadership from the Center.

The recent National Research Council report "Downstream" (NRC 1999) raised this point in several places. It called for a senior scientist (p. 16 and p. 129), and an independent Science Advisory Board, or SAB (p. 9). The panel reporting here understands that attempts to constitute a SAB have been unsuccessful to date. The Acting Director of the Biological Resources Program told this panel that the several review panels focusing on specific areas are intended, in part, to provide some of the needed outside input. However, an outside review panel still has a limited view of the ecological system and of what the Center is and should be doing. Also, this panel may not fully understand all aspects of matters on which it is commenting. The whole situation under which the Center operates is quite complex. The members of a SAB would be able to become familiar with the ecology of the system and the Center's science program over several years. This would lead to sounder advice than advice received from short-term panels focused on a restricted sets of issues.

3.1.2 Incorporate Scientific Direction into the Monitoring Program.

> **RECOMMENDATION:** Appoint the Scientific Advisory Board described in the Long-Range Strategic Plan. The Center also should employ a chief scientist. Both of these suggestions have been made before, most recently by the National Research Council.

The Center's Long-Range Strategic Plan clearly recognizes the need for informed scientific review; some scientific leadership also is needed to achieve the level of cooperation across disciplines envisioned by this review panel. National Research Council recently completed a review of the entire Adaptive Management Plan and the Center's role in it. That review stressed the need for scientific leadership in the Center, and in the review process, as by a Science Advisory Board. This panel endorses the recommendations of the NRC, employment of a chief scientist by the Center, and appointment of a SAB. A senior scientist could foster the cooperation between the various perspectives, thus implementing a whole-corridor ecosystem view.

3.2.1 There Appears to Be Little Integration Across Disciplines.

There appears to be little effort at coordination between various parts of the Center's program. Vegetation sampling is not tied to hydrology through the stage discharge and other hydrologic and sediment models being developed by the physical process group. Bird sampling and vegetation sampling are not using standardized cover type descriptions and vegetation sampling methods.

Dam operations affect sediment transport and deposition; sediment presence and composition has a major effect on vegetation; vegetation has a major effect on which animals can live where. Logically, then, animal sites should be the same as or a subset of the vegetation sites, and the vegetation sites should be the same as or a subset of the sediment sites. To determine ecosystem effects of altered dam operations, the sites and responses evaluated should be highly coordinated. Although there have been some individual attempts at this, there is generally little evidence that integration is occurring.

3.2.2 Ensure Integration Across Disciplines.

> **RECOMMENDATION:** Encourage cooperation, including shared sampling sites and joint river trips, among investigations of hydrology, sediment transport, fisheries, vegetation, and terrestrial animals. Include specific requirements for such cooperation in RFP's.

The Center needs to develop a policy to assure cooperation, as suitable, between and within the physical and biological resource programs. A mandate for coordination from the Center's Director would be helpful. However, an admonition to cooperate probably will not be enough. The cooperation probably will have to be required as a part of Requests for Proposals, by a requirement of some joint river trips, and inclusion of resources in budgets to facilitate joint working meetings. A Chief Scientist could foster the cooperation needed to develop an integrated, whole-corridor research and monitoring program.

One way that cooperation could be fostered is through use of jointly evaluated sites, based on the randomized grid recommended by this panel. Some points might only be used for evaluating vegetation cover from remote sensing. At a suitable subset of these points, certain sediment determinations also might be made. At a further subset of the sediment sites, vegetation also might be evaluated using fast protocols. It might also be appropriate to extend such cooperation to the cultural program; others may be able to judge the possible value of some close linkages between the physical, biological and cultural programs with the socioeconomic program.

3.3.1 There Appears to Be No Mechanism to Ensure Long-term Comparability of Monitoring Data Across Contractors and Center Personnel.

The Center has stated that it plans to execute a substantial portion of its research and monitoring with contracts, some of substantial duration. All parties acknowledge that a defensible long-term record of responses is essential for evaluating action taken under the Adaptive Management Plan. Evaluation protocols must be the same for each contractor if data are to be comparable across contracts.

3.3.2 Ensure Long-term Comparability of Monitoring Data Across Contractors and Center Personnel.

RECOMMENDATION: Develop protocols for evaluating responses and selecting study sites before any further proposals for terrestrial studies are requested, and ensure that new contractors are properly trained in these protocols.

The Center, not individual investigators, should be in charge of what responses to evaluate, and the protocols used to evaluate them. Protocol development and specification should be viewed as having high priority. Otherwise these will change each time investigators change, precluding the existence of a long-term data record on any response.

3.4.1 The Center Has Focused on Short-term Events, Rather than Long-term Responses.

The responses of the terrestrial ecosystem may be much slower than changes in dam management or flow regime. Most biological effects of a particular dam operation cannot be evaluated shortly after the event. Although there will be some immediate responses to extreme events such as major floods or a "spike flow," other responses will play out over long, multi-year time scales. Perennial plant responses may take years to decades; many animal species can respond only after the plants have responded. Placing most of the monitoring emphasis on short-term responses to such management actions can overemphasize transient effects and overlook long-term responses.

Some features of sediment respond to changes in dam operations in a matter of hours and days, and these changes can be determined almost immediately after flow returns to lower levels. Other features of sediment, such as its storage in and transport from debris fans work out over decades or even centuries. Past work shows that some immediate effects on sediment may be very short-lived.

Just as there is a long-term sediment response, the full effect of changes in dam operations on the biota can similarly take long periods of time. Flora and associated fauna respond in an obvious and predictable way to an intense perturbation such as a sustained, scouring flow: they disappear everywhere below the high water line. This was the case during nearly annual pre-dam spring floods, and repeated itself during the emergency high flows in 1983 - 1986. One experimental spike flow in 1996 had substantial effects on annual plants and their seed bank (Kearsley and Ayers 1999), but apparently was not of sufficient duration or flow to cause extensive scouring. The effect on woody vegetation was therefore modest. Most higher plants have cycles of growth and reproduction that take one year at the shortest and decades at the longest. Terrestrial animals, be they insects, birds or mammals, can respond to the major consequences of dam operations mainly through their responses to changes in the vegetation. In some cases they must immigrate – perhaps from great distances – into newly vegetated areas before they can become established. Thus the effects of dam operations may manifest over very long time periods.

These biological realities have major consequences for detecting the effect of dam operations on the terrestrial flora and fauna: Many things stakeholders would like to know about the consequences of dam operations simply cannot be known with any degree of certainty. To evaluate moderate changes in the dam operating criteria, the dam outflow would have to be operated under one set of operating criteria for at least 10 years and vegetation monitored, then one specific feature of that operating criteria would have to be changed. After the new operating criteria had been in place for several years, monitoring MIGHT detect some changes in flora and/or fauna between pre- and post-change. However, inferences to the vegetation changes having been "caused" by the change in dam operations would not be obvious without other studies and controls. For example, vegetation could also be responding to global climate change; it could also result from continuing local or regional changes unrelated to dam operations. For example, many bird species migrate; a decline in a bird species in the Grand Canyon could be due to changes in other parts of their range. In short, establishing unarguable links between terrestrial ecology and dam operations is difficult, if not impossible, in the case of moderate changes in the flows from the dam. Sustained, major floods are another matter, but what constitutes a sustained major flood is probably something between the spike flow of 1996 and the emergency floods of 1983 - 1986; i.e., a large range of flows.

The panel was supplied with an unnamed document dated 6-10-98 which lists Management Objectives (MOs) and Information Needs (INs) of the Adaptive Management Work Group (AMWG). The panel understands that the Technical Work Group of the AMWG has redrafted the INs, and perhaps the MOs, with an intent of clarifying them. Many of the INs are subject to the criticism above, i.e. they are calling for information that cannot practically be obtained directly, given the long time lags in the system. MOs 1 - 10 apply to aquatic resources, which is not the focus of the panel reporting here. MOs 10 - 16 relate to terrestrial resources, but 14 and 15 apply exclusively to the Kanab Ambersnail, which is the topic of Section 3.7.

The INs listed under MO 12 are evaluated here to illustrate the points made above as well as others; the other MOs have parallel problems.

- IN 12.1 "Identify terrestrial species potentially affected by dam operations and determine effects on distribution, abundance and population structure."
  COMMENT: This applies without qualification to every animal from a mite to a mountain lion, and every plant from a small grass to Goodding willow. It is practically impossible to determine the effects of dam operations on even one of these species under moderate changes in dam operations for the reasons given above. Further, there probably are terrestrial species yet to be discovered, an important reason for inventory (suggested elsewhere).
- IN 12.2 "Determine species' natural ranges (pre- and post-dam)."
  COMMENT: Pre-dam data are very thin; both pre- and post-dam distributions have been impacted by intentional and unintentional introductions, e.g., desert bighorn.
- IN 12.3 "Determine historic age class distribution (pre- and post-dam)."
  COMMENT: Pre-dam data are very thin. Is it assumed that one post-dam age distribution will apply for all time? Age distributions would fluctuate over time even in the absence of the dam. Is this meant to apply to each species? If not, to which ones?
- IN 12.4 "Assess natural range and age class disruption, changes, constraints, probable long-

term viability implications to species; assess alternate habitat, ecology associations (specifically age class); and ecosystem associations."
COMMENT: Disruption of what? By what? Dam operations, changes in dam operations, or something else? The problem of associating observed changes of some species with dam operations, discussed above, may be especially severe for this IN. This IN clearly advocates the need for long-term studies.

- IN 12.5 "Determine the impacts of alternate operating criteria on ecosystem and ecology requirements of each species."
  COMMENT: The problem of associating observed changes with dam operations, discussed above, is especially severe for this IN. Also, it is necessary to know the requirements of each species before such impacts can be determined. This is an argument for a preliminary inventory and data gathering (Section 2.2.3). "Alternate operating criteria" could mean a wide range of things.

3.4.2 The Center Needs to Communicate to Interested Parties How Slowly Biological Systems Respond to Some Aspects of Dam Operations.

RECOMMENDATION: Have the Adaptive Management Work Group and its Technical Work Group incorporate a long-term perspective into their information needs. This perspective should also be incorporated into monitoring plans and methodologies.

This amounts to a substantial teaching task. In order for this to be doable, the members of the AMWG and the TWG need to be willing to understand the limitations of science relative to their desires for information. A chief scientist and/or Science Advisory Board could play critical roles in communicating what is and what is not possible to ascertain within the context of varying dam operating criteria. It is equally important that the people in these groups recognize that although some physical processes respond almost immediately to changes in river flow regimes, other processes reflect their entire prior history. For example, some sediment may be moved to higher elevation by large flows, but other sediment may reside in debris fans until sustained high flows have a chance to rework the fan.

3.5.1 Insufficient Emphasis Has Been Placed on Developing Models That Will Predict the Effect of Dam Operations on Terrestrial Ecosystems.

Documenting changes in terrestrial communities is one thing; attributing those changes to dam operations is another. Development and use of ecosystem models will enhance understanding of the terrestrial ecosystem, and how it might respond to new perturbations. It will also help these responses to be separated from responses to other stressors, such as global warming or invasive species.

Development of ecosystem models has several values. It can help identify gaps in the knowledge; reveal deficiencies in past or planned data gathering; provide a reasoned basis for extrapolating to situations which have not yet been examined. On the other hand, extrapolation from developed models to situations far outside the conceptual basis of the model, or far outside the existing calibration data can badly mislead managers and other users. The existing sites and data series associated with them may have their greatest value for model development. These models need not initially be quantitative or specific. A conceptual model that serves as a hypothesis about important ecosystem components, linkages, and processes would be enormously helpful (see Section 2.2.2).

The Long-Range Strategic Plan (GCMRC, 1997) clearly speaks of the value of model development and provides a general basis for how models might be structured. Some modeling work may have been done for terrestrial resources, hinted at by a Center web page, but the panel reporting here has not seen any of that effort, if it exists.

Josh Korman described a model of the aquatic resource that is under active development by Ecometrics. The terrestrial components of that model were very undeveloped. That model perhaps should be expanded to include the terrestrial resources at the same level of detail as is planned for the aquatic resources.

3.5.2 Develop Ecosystem Models That Will Predict the Effect of Dam Operations on Terrestrial Ecosystems.

RECOMMENDATION: Develop a terrestrial ecosystem model with the same level of detail as the current aquatic model. Such a model, linked with field work on specific ecological relationships and ecosystem responses, is probably the only way to address "what if" management questions regarding dam operations.

Modeling has been successfully applied to explaining sediment transport and deposition in the corridor, and many other phenomena elsewhere. Even though modeling can be very useful, it probably can not provide defensible answers in the foreseeable future to all of the information needs which have been expressed. Nevertheless the development and use of ecosystem models will enhance understanding of the terrestrial ecosystem, and how it might respond to new perturbations. Such a modeling effort may reveal significant gaps in the ecological understanding which underlays accurate modeling. A caution: The proposed device for drawing warmer water from near the surface of Lake Powell could change temperature so far outside the range of currently available data from the main-stem corridor that any model-based results predicting the effect of changing the temperature regime could easily be unreliable. Models can provide very accurate predictions when they are founded on well understood relations. When complex ecosystem models contain quantities which must be estimated from field data, they may function well only in circumstances similar to the data ranges which were used to calibrate them; such models should be used for extrapolation only with great care.

3.6.1 The Effort Dedicated to the Kanab Ambersnail Is Out of Proportion Compared with Work on Other Field Components.

A great deal of time and research effort currently is being spent on studies of the Vasey's Paradise snail population. In addition, experimental translocations are underway to determine if this snail can be established at other sites. This intensive work is being conducted because of the belief that the Vasey's Paradise snail is a member of the endangered Kanab Ambersnail. The panel was informed, however, that recent genetic research suggests that the Vasey's Paradise population is not the Kanab Ambersnail, but is in fact a distinct, single-site endemic population. If this is true, the level of effort being expended on monitoring the Vasey's Paradise population is inappropriate, and the translocation program – which could be harmful to other endemic snail populations – may be unnecessary.

Another panel, chaired by Dr. Reed Noss, reviewed work on the Kanab Ambersnail (Noss et al. undated). It recommended doing substantially less intensive monitoring of that population. It made several other strong recommendations which have not been implemented.

3.6.2 The Center Should Support the Findings of the Kanab Ambersnail Review Panel.

> **RECOMMENDATION:** Confirm whether or not the snail population at Vasey's Paradise is actually the Kanab Ambersnail. Reduce the scale and frequency of the current monitoring effort and use minimally invasive methods. Minimize disruption of other endemic snail species caused by translocation of the Vasey's Paradise population.

The US Fish and Wildlife Service has applied a "10% take" rule in arriving at its opposition to sustained high flows. Currently the 10% take rule has been applied to a "take" of current habitat. Based on historical photos, little vegetation (i.e. habitat for the snail) existed below the level of the pre-dam annual flood stage (Stevens, et. al. 1997). At present, approximately 40% of the current primary habitat for the snail exists downslope from the pre-dam 10-year flood stage. Thus, a large portion of the current habitat would not exist if the dam had not curtailed levels of floods. Since application of the 10% rule to this current, augmented habitat may restrict management options for the whole river corridor, it is even more critical that the taxonomic identity of this snail be resolved.

3.7.1 The Center Has Several Immediate Needs Before a Monitoring Program Can Be Implemented.

Before a long-term monitoring program can begin, a detailed implementation plan should be developed to provide standardization and continuity to the monitoring program. Development of such a plan is a critical task, but will depend on resources not currently available. These needed resources represent obstacles to implementing recommendations made elsewhere in this report until they become available.

3.7.2 The Center Should Assign High Priority to Identifying and Overcoming Potential Obstacles to the Design and Implementation of a Terrestrial Monitoring Program.

RECOMMENDATION: The Biological Resources Program, in collaboration with other programs of the Center, should place high priority on developing and/or completing a number of products needed for development of a comprehensive monitoring program.

- Complete a Geographic Information System (GIS) coverage which defines the boundaries of the entire river corridor of interest for terrestrial and aquatic resources.
- Complete a current land cover map, preferably based on ground-truthed multi-spectral remote imagery.
- Select a random sample of spatially distributed study sites in the main-stem corridor using information generated by the previous two tasks.
- Develop and codify cost effective indicators and protocols for evaluating plant and bird responses to dam operations, but defer site selection until the main-stem corridor sampling has been completed.
- Develop protocols to ensure inter-disciplinary cooperation, and include such protocols in future Requests for Proposals (RFP's).

The panel's admonition to "cooperate across disciplines" (recommendation 3.2.2) and to "develop and codify cost effective indicators and protocols" (immediately above) should lead to some unconventional considerations, illustrated by what follows. The Center sponsors 30+ raft trips from Lees Ferry to Diamond Creek each year. When personnel on these trips are not occupied with their disciplinary responsibilities, with minimal effort, they could be trained to record sighting locations of desert bighorn sheep, apparent beaver borrows, water fowl, birds of prey, and perhaps their attacks, and similar sightings. Compilation of such reports across appropriate seasons could give a fairly accurate view of the respective resource. If such evaluation protocols were applied for a number of consecutive years, trends in the size of the respective resources could be detected even though accurate estimates of the associated population sizes probably might not be possible.

A preliminary version of this report was presented to the Adaptive Management Work Group at its meeting on May 11, 2000. At that time the panel learned that work already has begun on a few of the recommendations made above. Specifically, aerial imagery needed for the first two products mentioned immediately above has been obtained. Further, the panel has been informed that invitations recently were extended for the SAB, and that the Kanab Ambersnail Working Group currently is reevaluating the Center's entire effort on that and allied organisms.

4 - RESPONSES TO QUESTIONS POSED TO THE PANEL

4.1 Do the Methods and Sites Adequately Address Management Objectives for Terrestrial Resources?

RESPONSE: No. Some of the methods and sites are addressing the ambitious set of information needs in the management objectives for terrestrial resources. Current methods and sites do not provide adequate coverage spatially (poor representation of the river corridor as a whole) or taxonomically (focusing on a limited set of terrestrial animal species).

See Chapter 2 for the basis of the panel's response to this question.

4.2 Could the Current Monitoring Sites Be Augmented with Additional Random Sites to Serve as Index Sites for Monitoring by Geomorphic Reach?

RESPONSE: Possibly, with appropriate design considerations, but the panel proposes an alternative sampling design. Current sites have substantial promise as model development sites.

See Chapter 2 and Section 3.5 for the basis of this panel's response to this question.

4.3 How Does One Separate Effects of Dam Operations on Terrestrial Resources from Natural Variation in Those Same Resources?

RESPONSE: This is possible for some features of sustained extreme flow events, but is difficult and complex, if not impossible, given the variability of current dam operations and the temporal lags in responses of the terrestrial biota. We outline a monitoring and research framework elsewhere in this document that should approach this goal. Briefly, treatments need to be distinct enough in magnitude and maintained for sufficient periods of time to allow responses to dam operations to be distinguished from other non-dam related factors, such as climate change and natural spatial/temporal variability. Comparisons to other sites may serve as pseudocontrols. Ecosystem models offer some hope for exploring how flow manifests its effects.

See Section 3.4 for amplification and background for this response.

4.4 Are There Elements of Terrestrial Ecosystems That Need Further Understanding Before a Robust Monitoring Effort Can Be Developed?

RESPONSE: Yes, some elements such as arthropods, reptiles, and mammals need a much more current and complete inventory than presently is available. On the other hand, current information on birds and plants appears to be sufficient to develop a robust monitoring program if the objectives are clearly stated. The boundaries of the intended monitoring area probably should be expanded up some of the side canyons.

See discussions in Sections 2.1 and 2.2.3.

APPENDIX A: INDIVIDUAL REPORTS

Several members of the panel wrote comments related to their specific areas of expertise. Those reports are included here as presented by their respective authors. These reports should NOT be viewed as minority reports; the panel arrived at a complete consensus on every major point. The panel's intention is for the preceding body of our report to be of interest to a somewhat general audience; technical details have been deferred to here as much as possible. Readers with interest in such details will find them here. This appendix contains the following four individual reports:

A.1 Vegetation Studies in the Grand Canyon, by Gregor T. Auble and Alan H. Taylor;

A.2 Bird Monitoring, by John G. Blake;

A.3 Developing an Inventory, by David C. Lightfoot; and

A.4 Statistical Aspects of Monitoring Ecological Resources, by N. Scott Urquhart.

A.1 Vegetation Studies in the Grand Canyon

Gregor T. Auble and Alan H. Taylor

Existing Vegetation Studies.

Vegetation studies conducted under the Center's research and monitoring program have adequately described the distribution of species and plant communities at small spatial scales as they relate to dam operations, including the spike flow release. However, there are weaknesses in the design of these studies that reduce their effectiveness for identifying important vegetation changes throughout the Grand Canyon river corridor caused by dam operations that are occurring. Identifying the extent and magnitude of system wide vegetation changes is important because of food web linkages between vegetation and terrestrial and aquatic organisms. Moreover, future unexpected vegetation changes caused by such things as fires in now dense riparian vegetation, spread of pathogens in now large plant populations, invasion and spread of exotic species, or changes in woody plant abundance caused by an expanding beaver population are unlikely to be detected by the current intensive studies.

Cross-scale integration. Much of the previous work on vegetation has focused on plant population changes at small scales on debris-fan complexes. These small scales studies need to be integrated with a whole-system vegetation study to (a) summarize the overall status of vegetation; (b) evaluate how representative intensive study sites are ; and (c) provide a foundation to extrapolate processes and relations that are defined at the intensive sites. A whole system cover type map repeated at intervals of 5-10 years, in combination with randomly selected ground-verification plots to identify cover-type species relationships, would satisfy the need for a system wide description of vegetation. Moreover, a detailed pre-dam vegetation map should be made using historical aerial photographs to serve as an ecological reference for pre-dam vegetation characteristics. Such an ecological reference is important for assessing post dam patterns and processes. Some ideas for addressing these system-wide needs are outlined in Appendices A.3 and A.4.

Cross-discipline integration. In order to define functional relations between dam operations and vegetation response, it is essential to measure the physical variables that connect streamflow to site conditions that determine riparian plant response. Work at the Grand Canyon and elsewhere has established the importance of (a) inundation depth and duration (obtainable from plot elevations and a stage discharge relation or model); (b) sediment particle size; (c) disturbance (removal of vegetation biomass by hydraulic forces); and (d) sediment aggradation/degradation (changing plot elevation) as determinants of riparian vegetation distribution at both the cover-type and species levels.

There are several ways to better integrate physical driving variables to the riparian vegetation response. Cover type maps could be registered and overlain on the topographic surface of an existing hydraulic model. Locations (*x*,*y*,*z*) of individual sample plots could be overlain on the topographic surface in reaches with known stage-discharge relations. Coupling vegetation data collection to a 2-dimensional hydraulic and sediment transport model (such as those being developed for selected debris-flow complexes) provides even more information about the physical variables that connect dam operations to vegetation responses. At a minimum, elevation should be collected during all plot-based vegetation evaluations so dam operations can be connected to each sample site through stage-discharge relations.

Vegetation studies should also be integrated with those of wildlife populations. For example, bird species abundance is known to be related to vegetation composition and structure. Cover-type species composition associations developed in the vegetation work should be relevant for monitoring of bird populations.

Simplicity and model development. A simple and efficient way to identify and relate spatial and temporal vegetation changes to physical driving variables is to resample fixed-location plots arrayed along a physical gradient (repeated measures). For example, in a hydraulically simple reach, a belt transect orthogonal to the channel would array plots along an elevational gradient. Hydraulic models or stage-discharge relationships can then be used to connect river discharge with physical plot conditions (e.g., inundation, scour, deposition, etc.) determining vegetation responses. Such a sampling approach provides a basis for developing sound process-response models between streamflow and riparian plant species along the river corridor.

The current sampling approach is considerably more complex, is difficult to repeat, and the results may be difficult to interpret with regards to dam operations. Specifically, it will be hard to (a) disaggregate occurrence of individual plant species on plots and array them along physical gradients because plot locations are not being recorded; (b) distinguish changes in area and location of mapped cover type polygons from changes in the species composition of those polygons (e.g., is *Tamarix* increasing because polygons dominated by *Tamarix* are expanding or because *Tamarix* is becoming more dominant in the polygons that contain it?); and (c) interpret the unique histories of the very large number of polygons created by overlaying many years of polygonal coverages.

At the intensive study site level, fixed plot locations would simplify data collection and interpretation, especially in the context of a long-term multi-personnel monitoring effort. A series of belt or modified-belt (interrupted) transects could be used, or random plots could be relocated with GPS or total station from benchmarks. Certainly considerable attention should be given to how permanent plots are laid out in spatially complex and patterned situations such as the debris-fan complexes. Alternatively, the current scheme of polygonal mapping and re-randomized plots within mapped polygons could be used with GIS technology if plot locations and elevations were recorded.

Vegetation metrics and tradeoffs. Current vegetation sampling is largely focused on distribution and dominance as influenced by dam operations at intensive study sites. Given finite resources, tradeoffs are necessary regarding measurement variables, sampling intensity, and geographic scope. The scope needs to be expanded to include both the whole system and more intensive study sites. Sampling frequencies, however, might be reduced at both whole system (5-10 year intervals) and intensive study site (3-5 years) levels. Productivity measurements would require substantially more effort though they might ultimately be quite important in terms of food base for aquatic and terrestrial animal species. Basal area, especially of herbaceous species, is a very expensive way to characterize patterns of species distribution and abundance and it should be discontinued in a monitoring context. Cover is a reasonable surrogate measure. Furthermore, species presence/absence, can be obtained more quickly than cover which might allow many more plots to be sampled, and this measure may be more appropriate for identifying system-wide distributional changes caused by dam operations. Finally, cross-discipline integration needs to be better considered when choosing vegetation measurement variable(s). In particular, vegetation habitat variables for birds (Appendix A.2) should be an integral part of the vegetation monitoring program.

A.2 Bird Monitoring

John G. Blake

General Comments

The management objective for avifauna (MO 13) is a restatement of MO 11 (i.e., "Protect, restore, and enhance survival of native and special status species") and is therefore largely redundant (also redundant with MO 12 as birds are "wildlife" as well). The information needs described under MO 13 deal primarily with Peregrine Falcons, Bald Eagles, and the southwestern subspecies of the Willow Flycatcher. There is one statement about general "avifauna food chain associations" which could be applied to the bird community overall. Thus, objectives for a general monitoring program directed at bird populations are not well developed. Nonetheless, there are a variety of reasons why a monitoring program could be useful:

- Birds are an important and visible component of the river system (both aquatic species and riparian species); riparian birds have, for example, an important functional role as predators on herbivorous insects and aquatic birds serve as indicators of aquatic productivity, particularly in the upper reaches.
- Distribution and abundance patterns of terrestrial birds are closely tied to various structural and floristic components of the vegetation, which provides nesting sites and foraging locations, supports the resource base, and provides cover from predators. Consequently, changes in bird populations may serve as an indication of changes in vegetation and or productivity. From the latter perspective, studies on food-chain associations are warranted.
- Birds have been and continue to be central to the development of much ecological theory. Thus, information on population trends has intrinsic ecological interest.
- Many bird species have cultural significance, both to native groups and to the general public as well. Other species have achieved legal or conservation significance because of low or declining populations (i.e., species of special concern).

For these and other reasons, a monitoring program that considers bird populations as a whole might be justified, depending on the goals and objectives. As discussed elsewhere in this report, whether birds (or other organisms) can effectively serve as indicators of the effects of dam operations depends, to some extent, on the spatial and temporal scales involved. If, for example, the goal is to detect changes in the system caused by dam operations (e.g., changes in flow regimes), then it might be more appropriate and realistic to focus on changes in vegetation structure as these may be easier to measure and will largely determine the responses of birds. If a functional relationship can be established between aspects of the habitat and bird species distribution and abundance, then changes in vegetation may actually have predictive power with respect to bird populations. To achieve such a functional relationship will require actual density estimates of bird species in the various different vegetation types, something that would require a more intensive effort that is now devoted to the general monitoring.

If the goal is to simply keep track of (i.e., monitor) the status of bird populations in order to detect changes in relative population levels over time, then a general monitoring effort such as currently developed has merit. In fact, if dam operations actually follow a clearly defined sequence of flows (i.e., years of one flow regime followed by years of a second flow regime, with few if any alterations; temporal replications) then changes in bird populations may be tied to dam operations. To achieve such a goal (tying bird populations to dam flows) will be difficult given the many factors that affect bird population levels, quite apart from dam operations (e.g., overwinter survival of migrants) and the difficulties associated with control of dam operations. If a priori hypotheses regarding effects of flow regimes can be developed during the first sequence of years (under one flow regime), then predicted changes might be tested in a temporal sense through planned changes in the flow regime. Such a program would require a much longer time frame than is allowed by single-year RFPs. Predicted responses of birds may be better understood if functional relationships between birds and resources (insects), plants, and physical processes can be achieved. As discussed elsewhere, development of such relationships will require that all aspects of the system are studied at the same sites over the same time frames. Similarly, to develop functional relationships between birds and vegetation, it will be important to sample birds within replicates of each major vegetation type, both alone and in combination (e.g., OHWZ only; NHWZ only; OHWZ adjacent to NHWZ, if possible), to determine the possible synergistic effects of multiple habitats (e.g., birds may use one zone for foraging and one for nesting).

Comments on Current Sampling

Studies on the southwestern subspecies of the Willow Flycatcher (*Empidonax traillii extimus*) are largely dictated by the ESA and no comments seem called for, other than the amount of effort given to this “population” is out of proportion to its importance to the system. The single pair that apparently remains can not be considered a viable population in any sense.

There are two basic components to the general monitoring program for birds: winter bird surveys and breeding bird surveys. The winter bird surveys are relatively simple and provide good data on the distribution and abundance patterns of aquatic birds (the main focus). Bird numbers are higher in the upper reaches, closer to Glen Canyon Dam, appearing to show a clear relationship to the productivity of the aquatic system. The sampling should be continued.

The breeding bird surveys are more extensive and challenging, as they involve sampling birds in a variety of different habitats. To a large extent, the current system of point counts should be sufficient to detect a large part of any significant changes in bird numbers across years. The patches were not randomly selected but do seem to be well distributed throughout the system. If the monitoring program institutes samples at additional points (as discussed elsewhere in this report), it would seem advisable to retain many of the current bird sample sites for a number of years to ensure continuity. Current study patches were selected to be representative of “good” habitat for birds. This has the advantage that it increases the likelihood of detecting more individual birds, thereby allowing detections of changes over time (if species are too rare it is difficult to statistically evaluate any changes). Selecting “good” patches has two disadvantages: not all parts of the system are well sampled; and samples have not been selected randomly, with consequent statistical implications.

A few remarks on methods of analysis are in order. First, it seems much more appropriate to analyze point-count data at the level of the patch rather than at the level of point. Points within a single patch (or within a single type of vegetation within a patch) are clearly not independent samples with respect to the system even if individual birds are not counted at more than one point. The patches seem to be more or less clearly defined units that are separated, often by substantial distances, from neighboring patches. Second, detecting significant changes in bird populations may be difficult for many species if the species are not common. By grouping species into functional groups or guilds (e.g., based on nest site selection, food resources, foraging locations) it may be easier to detect changes in abundance and to relate those changes to changes in the environment.

Two alternatives or additions to the general monitoring also come to mind. First, as an alternative to community-wide assessments (i.e., identifying all birds, which requires a continuous supply of well-trained observers backed by a training and testing program) one might pick several focal species that are common and/or representative of specific aspects of the vegetation (e.g., Lucy's warbler, common yellowthroat) and concentrate monitoring on those species. It is easier to train observers to recognize a few species and common species may be more suited for detecting changes in population levels. A second alternative would be to focus on reproductive success of breeding birds. If the canyon riparian system is indeed serving as a refuge for species, including many migrants, then reproductive success should be sufficient to maintain or increase the population (i.e., the canyon would serve as a source rather than as a sink). Although reproductive success is perhaps the best measure of health of the system, it is both time consuming and labor intensive, making it less suitable for a baseline monitoring effort. It could be useful as an additional component to a broader monitoring system (particularly for the development of any functional relationships between vegetation, resources, and bird populations).

Finally, whatever methods are used and whatever the objectives are, results should be published in peer-reviewed journals. Data are relatively useless as long as they remain in final or interim reports that simply take up space on shelves. Publication in peer-reviewed journals also has the benefit that there is, in a sense, a continuing peer-review of the monitoring program. If the results are not suitable for publication then it is not likely that they are suitable for describing conditions in the canyon.

A.3 Developing an Inventory

David C. Lightfoot

A Grand Canyon corridor-long terrestrial riparian biological resources inventory and long-term monitoring program should be initiated soon. Such an inventory and monitoring program could take many forms and emphasize many different biological resource elements. Below is an example or model for such an inventory process that includes those biological resources that are important and reasonable to inventory and monitor relative to the Center's objectives. This proposed inventory and monitoring program is provided only as an example to help the Center develop an actual program that integrates similar spatial, temporal, and taxonomic aspects. The inventory program presented here is within the current financial and logistic scope of Center's funding and activities. I interviewed many of the biologists who are currently conducting ecological studies along the canyon corridor to ensure the feasibility of the logistic and taxonomic scopes of this example program. This example inventory and monitoring program is presented below in an abbreviated outline format to emphasize the key goals, elements, and procedures at a glance.

Biological Resources Inventory Survey

Description

Multi-reach, multi-site, intensive inventory for representative taxa.
Not designed for rare, or threatened or endangered taxa, but inclusive of those.
Vascular plants, vertebrates, arthropods, mollusks.
Coordinate with physical and cultural resources.

General goals:

- To document the occurrence and relative abundance of representative taxa over space (sites/water-level zones corridor-long) and time (seasons and years).
- To provide monitoring data for long-term trends rather than for specific treatments (single water release events).

Site selection

- 30 sites total: 10 sites in each of 3 reaches of the Colorado River/Marble Canyon, Grand Canyon; 10 sites in upper reach, 10 sites in middle reach, 10 sites in lower reach.
- Each site is located on one side of the river.
- Each site measures 300 meters along the river, partitioned into three water-level zones:
  - a) old high-water 100,000 to 300,000+ cfs
  - b) new high-water 20,000 to 100,000cfs
  - c) fluctuation zone <20,000cfs

Site locations selected utilizing a variable grid-based random sampling design (see Appendix A.4); weighted to include a greater proportion of sand beaches and/or other environments of special interest.

Existing biological resource monitoring; incorporate existing sites utilized by Stevens (1992), Kersley (1994); 8 sites; Phillips (1970), lower reach only, 3 sites; Waring (1996) and Pucherelli, large scale repeat aerial photography. Take advantage of existing and potentially long-term data sets.

Survey timing, frequency, and duration.

First three years:

4 sample periods each season (winter-January, spring-May, summer-July, autumn-September).

Two, 15 day boat trips each period; sample 10 lower reach and 5 of the middle reach sites during the first trip in winter and spring, then sample the remaining middle and upper reach sites on the second trip. In summer and autumn, sample 10 upper reach and 5 middle reach sites during the first trip, and the remaining middle and lower reach sites during the second trip. This schedule will accommodate elevation/seasonal variation across the corridor. Visit each site for one 24 hour period, mid-day to mid-day.

Years 4 and 5:

Subjectively visit other locations along the river corridor as needed to survey environments not represented in the 3-year inventory. Number and location of sites, and timing, frequency and duration of visits depending upon needs. Continue visiting the 30 inventory sites, but only during the fall and spring. Or, temporarily discontinue visiting the 30 inventory sites until appropriate to resume for long-term monitoring needs (e.g., every 5 years).

Note: The total number of sites could be doubled (60), or tripled (90), etc.

By visiting different sets of 30 sites during different years, instead of repeat visits to the same 30 sites over a period of years. Tradeoffs: better representation of taxa/site with multiple year samples/site vs. better statistical power with a larger number of sites, each only surveyed for one year.

Staff

Senior staff members (full-time); one plant ecologist/botanist, one animal ecologist /vertebrate zoologist, one animal ecologist /arthropod-mollusk ecologist, 3-4 technicians (full-time and/or seasonal).

Facilities Support

Project administration, computers, cartographic and photo processing, lab space, museum facilities, information (data) management, consulting expertise, boat trips, administrative support for permits, etc. (GCMRC, USGS, and others, e.g., NAU).

Flora

Each site visit record every species and relative abundance in each water-level zone. Use relevé method in each water-level zone to quantify canopy cover values by species. Collect voucher specimens as needed, with a goal for a comprehensive collection of all species known from the river corridor.

Products

Species list, relative abundance, foliage canopy cover by species, seasonal occurrence of each species by site, water-zone, season, year.

Voucher plant collection, and photographs of all plant species known from the river corridor.

Mammals

- Large animals (deer, sheep, cats, etc.)

Each site visit record observations of animals, tracks, scat, or other sign by site, water-level zone, season, year.

Beaver: record beaver impact by plant species used, and number and sizes of stems observed cut.

- Small terrestrial mammals (mostly small rodents)

Each site visit (night), sample rodents with Sherman live-traps, one line, 10 traps every 30 meters parallel to the river in each water-level zone. Record numbers of individuals by species by zone.

- Bats

Each site visit (night), record bat calls with Anabat detector. Determine presence of each species for entire site.

Products

Species lists, and relative abundance, seasonal occurrence of each species by site, water-level zone (except bats), season, year.

Photographs and/or voucher specimens as needed.

Birds

Each site visit record every species and counts of individuals in each of the water-level zones. Use central point or transect (rodent trap lines) observation/count/distance methods, and/or general observations.

Products

Species list, and relative abundance, density, seasonal occurrence of each species by site, water-level zone, season, year. Photographs and/or voucher specimens as needed.

Reptiles and Amphibians

Each site visit record every species and counts of individuals in each of the water-level zones. Use transect methods (rodent trap lines), and/or general observations.

Products

Species list, and relative abundance, seasonal occurrence of each species by site, water-level zone, season, year. Photographs and/or voucher specimens as needed.

Invertebrates

Ground-dwelling Arthropods

Install 0.5 liter plastic cup pitfall traps at each of the rodent trap stations in each of the 3 water-level zones per site. Open traps at the start of each visit, collect samples, and close at the end of each visit (bait traps or not).
General collecting of ground-dwelling arthropods during each site visit, recording habitat and water-level locations.
Collect voucher specimens of all taxa.

Plant Foliage Arthropods

Each site visit, sweep the foliage of dominant plant species with an insect sweep net. Sweep the equivalent of 20 sweeps/plant species/water-level zone. Bag samples, take back to lab to sort, identify and tabulate counts of arthropods by species per sample. Collect voucher specimens of all taxa.

Flying Insects

Each site visit, set one malaise trap in center of each water-level zone at start of visit, sample insects and remove at end of visit.
Each visit, set one light trap malaise at each malaise trap location, and run at night. Take all samples back to lab to sort, identify, and tabulate arthropod counts by species.
Collect voucher specimens of all taxa.

General Collecting

Each site visit, search each zone for arthropods, collect, take specimens back to the lab for identification.
Collect voucher specimens of all taxa.

Products

Species lists, and relative abundance, seasonal occurrence of each species by site, water-level zone, season, year. Host plant and habitat relationships. Photographs and/or voucher specimens as needed.

Site Characteristics/Conditions

Low-level Aerial Photographs

Take initial series of multi-spectral low-level aerial photographs for each of the 30 inventory sites.

Use image processing techniques to map and quantify ground cover of geomorphic/soil surfaces and vegetation cover types.

Partition analysis by water-level zone per site.

Products

Ground cover quantified by geomorphic surface and soil cover by site, water-level zone.

Vegetation foliage canopy cover quantified by site, water-level zone (and to species level for large perennial plants).

Main-Stem Corridor Long-Term Monitoring of Biological Resources

Methods

Use same 30 inventory survey sites. Or reduce number of sites if appropriate.

Use same inventory survey protocols. Or reduce/simplify protocols if appropriate.

Reduce site visits to twice each year, spring (May) and autumn (September). Or once each survey year if appropriate.

Use repeat low-level aerial photography to monitor changes in site characteristics and conditions.

Repeat site visits and aerial photography as needed depending upon monitoring goals (e.g., repeat every 5 years, or every 10 years, etc.)

Products

Repeat, comparative data for plant and animal species presence and abundance by site and water-zone over whatever time period interval is chosen.

Repeat, comparative data for geomorphic/soil/vegetation cover by site and water-zone over whatever time period interval is chosen.

A.4 Statistical Aspects of Monitoring Ecological Resources

N. Scott Urquhart

Most of applied statistics has evolved within contexts oriented toward experimentation, wherein the investigator controls the conditions to which the research material is exposed. "Treatments" and "Experimental Units" have fairly clear meanings in such settings. By contrast, most field ecology is observational; treatments usually do not exist, and what constitutes the observational unit often is obscure. Furthermore the word "sampling" takes on many meanings in such contexts - meanings ranging from site selection to the collection of biological material to the selection of the part of collected material to submit to laboratory analysis. The U.S. Environmental Protection Agency (EPA) started the Environmental Monitoring and Assessment Program (EMAP) about 10 years ago. It was intended from its inception to produce statistically defensible evaluations of the condition of ecological resources in a region, where a region could be the size of several states, and was especially concerned with being able to detect small (like 2% per year) continuing change (trend) in the condition of the ecological resources.

Questions asked by ecologists starting this program revealed some large gaps in the statistical concepts and tools needed to conduct such surveys of ecological resources. Statisticians[3] associated with this program have developed a number of concepts and tools to fill these gaps. Three specific topics from this work appear to be especially relevant to the work of the Center: The structure of ecological monitoring surveys through time; randomized grid-based site selection; and support regions, namely associating suitable evaluation areas with selected sites which are points.

A.4.1 Structure of Ecological Monitoring Surveys Through Time

Urquhart and Olsen developed a presentation entitled the "ANATOMY OF SAMPLING STUDIES OF ECOLOGICAL RESPONSES THROUGH TIME." In it they have identified the principal parts of survey designs of ecological resources through time as being a Monitoring Strategy and an Inference Strategy. The Monitoring Strategy is composed of the Universe Model, Statistical Population, Domain Design, and Response Design; the Inference Strategy contains the Survey Design, Temporal Design and Quality Assurance Design.

In the context of terrestrial studies in the Grand Canyon, the universe model would be a two-dimensional grid system of any desired resolution over the entire river corridor. (The third dimension would be elevation, an attribute of each point, which could be viewed as a response.) The statistical population would be a response of interest at the collection of all points in the river corridor at a point in time. The Domain Design describes what comparisons in the population have what subject-matter meanings, and cannot be further described here without a specific monitoring question. The Response Design describes all of the protocols for evaluating the response once the investigator(s) arrive at the site specified by the Survey Design. This design component is so important for the Center that section A.4.3 is devoted to it. The Survey Design concerns how "units," points in the

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[3]Anthony R. Olsen, US EPA, Don L. Stevens, Dynamac (an EPA contractor at EPA's laboratory in Corvallis, OR), and N. Scott Urquhart, Statistics, Oregon State University.

Grand Canyon, should be selected; the next section is devoted to how this can be done while simultaneously achieving several desirable and needed conditions. The Temporal Design records planned revisit schedules, if revisits are planned. For the Center revisits might be specified as occurring several times per year, or only once every few years. The Quality Assurance Design relates to all of those activities which are concerned with achieving initial quality with the resulting data, and with maintaining that quality through the storage, retrieval, and use of that data.

The material presented above has been presented at several professional meetings, by both Olsen and Urquhart; abstracts have appeared several places. Urquhart has taught an advanced course on environmental sampling (ST 571) as a part of the offerings in environmental statistics of the Department of Statistics, Oregon State University. The anatomy described above has served as the organizing structure for that course. A PowerPoint presentation on this topic, converted to a web presentation, is available on the site for that course:

http://osu.orst.edu/instruct/st571/urquhart/anatomy/

A.4.2 Randomized Grid-Based Site Selection

Parts of ecology have a tradition of picking sites which are viewed as "typical" in the perspective of the person or group doing the picking. Ample evidence exists showing that inferences based on such sites can produce very misleading results for inferences to the condition of a resource in an area. See, for example, Peterson, Urquhart, and Welch (1999).

Yet purely randomly located sites ordinarily exhibit clustering, regardless of scale or number of sites. Such patterns become troublesome when subsequent users of data gathered at such points want to use the resulting data to draw inferences about subregions; the clustering may produce a deficiency of sites in an area which, based on its size, should have more points. Practically, random selection needs to be slightly restricted to achieve a degree of spatial balance. Some resource evaluation has been done on a strict grid (Forest Service, for example), but such site selection encounters two problems: some periodic phenomena whose period matches the grid spacing will be entirely missed, and points get progressively closer as the grid moves north (in the northern hemisphere).

In large-area surveys, there may be legitimate reasons why some parts of the resource may need to be sampled more intensively than other parts. It also frequently occurs that some responses of interest may be much more expensive to evaluate than are other responses. EMAP has evolved within EPA for about ten years. Statisticians associated with this program have addressed the problem of how to select sites for ecological and environmental surveys which would be spatially balanced, proportional to the resource, yet accommodate variable sampling intensities and nesting of responses, such as by cost. Their work has been implemented in approximately 200 survey designs, many of which have been executed. These range from ones having points distributed within a few meters of each other to one which has 600 points distributed on streams and rivers in 12 western states. An especially illuminating example appears in Stevens (1997). Some of its features are summarized below as an illustration.

Southern California Bight (SCB), extends along the west coast of the U.S. from Point Conception (near Santa Barbara) to the US-Mexico border, a distance of approximately 400 km. A variety of programs were spending over 5 million dollars per year to monitor the marine environment of the SCB by 1990. There was little or no coherency among these programs because they were conducted by different agencies, with differing needs and mandates; this made region-wide inferences difficult and of questionable value.

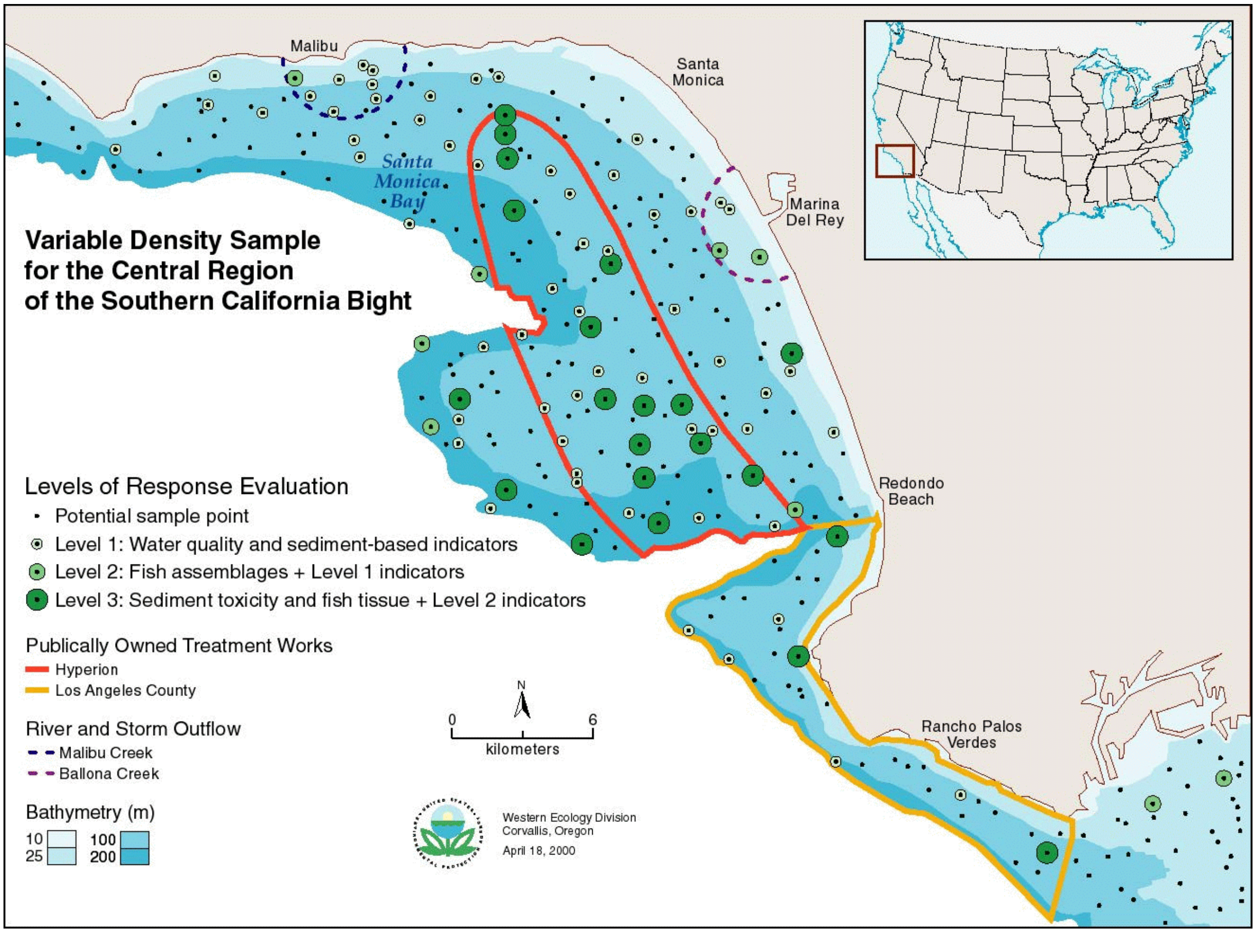
The Southern California Bight Pilot Project (SCBPP) was created in 1993 by 12 agencies involved in regional marine sampling efforts. This project has the broad objective of assessing environmental condition of the entire SCB. Initial discussions of the design needed for the project identified several important features:

- Substantial natural biological variation related to ocean depth and latitude led to the definition of 3 subpopulations defined by depth zone and three overlapping ones defined by latitude.
- Several of the sponsoring agencies are Publicly Owned Treatment Works (POTWs) with off-shore outfalls. The POTWs have a legal requirement to perform monitoring near the outfalls. These considerations led to the definition of 10 overlapping subpopulations with minimum sample size requirements.
- A variety of indicators were to be collected to assess environmental condition. The indicators were grouped into three levels that reflected increasing costs of collection and processing:
  - Level 1 consisted of water quality, sediment characteristics and benthic invertebrate assemblages, and was to be collected at all sites.
  - Level 2 consisted of fish assemblages, fish pathology and marine debris, and was collected at a subset of Level 1 sites.
  - Level 3 consisted of sediment toxicity and fish tissue contamination, and was collected at a subset of Level 2 sites.
  - Furthermore, budget constraints placed an inflexible upper limit on the total number of sites, and on the number of laboratory analyses that could be performed to obtain the Level 2 and 3 indicators.

The considerations, coupled with precision considerations, led to the following design constraints:

- A maximum of 270 Level 1 sites, distributed so that each of the 10 subpopulations had at least 35 sites.
- A maximum of 140 Level 2 sites, distributed so that each of the three latitude zones, each of the 3 depth zones, and the combined outfall zone had at least 35 sites.
- A maximum of 80 Level 3 sites, split approximately equally between the outfall zones and the remainder of the SCB."

The resulting distribution of sample points in middle part of the SCB is shown in Figure A.1 (an adaptation of Stevens' Figure 12).



projects/emapgis/urquhart/californiabight/figure12-4.ai
4/18/00 smp

Figure A.1. A section of the Southern California bight sample showing actual sample point locations. The size of the circles around a point indicate the level of responses evaluated at that point. (After Stevens 1997)

The technology of how the sites are selected is detailed in Stevens' paper. In principle it functions this way: A moderately fine density of points is laid down - (he used a triangular grid with an area of 1.86km^2 around each point.) - and a surrounding area called a tessellation is associated with each point. The mechanism for constructing the points provides a basis for identifying each point and its associated area by a hierarchical index like 346445242, where points which share the first six digits are closer in space than those which share only the first five or the first four. Variable density is achieved by attaching an relative density to each point - numbers like 1, 2, and 4 - where the latter indicates points which should be 4 times more likely to show up in the sample than those with a relative density of 1. All of the tessellation areas in the study area are hierarchically randomized, that is they are randomized initially using only the first digit of their identification, then within this first randomization, points are randomized by their second digit, and this is repeated with each successively lower order digit in the identifier until it has been done for all of the identifier digits. A sampling line then is constructed with points ordered along it as the hierarchical randomization has produced; each point is represented by a length which is its desired relative inclusion density; this is where the relative weights, like the 1, 2, and 4 above, are used. The total length of this line (L), including the effect of the relative densities, is divided by the desired sample size; this provides a unit of length ($l = L/n$) on the sampling line. A point is randomly located between 0 and l; call this p; successive points on the sampling line occur at $p + l$, $p + 2l$, ..., p + (n-1)l. This process selects a randomized subset of the available tessellation areas with the desired properties. The final points are randomly located in the respective tessellation areas.

The points selected this way represent the densest (level 1) set of points. Select a less dense (level 2) subset this way: preserve the (randomized) order of the level 1 points, but place them on a new sampling line. Space these points n_2/n_1 (where n_i = # level i points). Pick those points where integers occur on the sampling line. For example, if $n_2/n_1 = 0.25$, this process would lead to the level 2 points being every fourth level 1 point. If n_2/n_1 is not an integer, like 270/140 = 1.929 in the illustration, the selection method described would every other level 1 point as a level 2 point most of the time; occasionally adjacent points on the secondary sampling line would be picked. This process can be repeated to pick the level 3 points as a subset of the level 2 points. This description applies to equal probability subsetting; more generally the probabilities a point in one level is selected for the next higher level can vary depending on characteristics of the points.

If the original points and tessellation areas were represented in a GIS then the selected points can be mapped back onto a correspondence to actual points on the ground. These can then be placed on maps of an appropriate scale, if needed, or be located with suitable land or marine location devices, like GPS where it is available.

If the initial GIS coverage has been represented in a suitable (area preserving) map projection, and the grid and subsequent transformation back into map locations is done with the inverse of the same mapping projection, then this site selection process accommodates curvature of the earth.

A.4.3 The Response Design = "Plot" Design (Support Regions)

Protocols for evaluating responses may have very deterministic or systematic components; the needed randomness resides in the Survey Design. The Response Design concerns how the response is evaluated once the investigator arrives at the point specified by the Survey Design. Some responses, such as water chemistry, or the percentage of fine sediment in a soil core extracted at the point, effectively exist at a point. Others need a support region for their determination of a response (Stevens and Urquhart, 2000). For example, a support region of possible interest here could be a transect two meters wide centered on the sampled point (site), perpendicular to the river, extending from the river to the upper edge of the old high water zone. This illustrates a simple, but important matter: Although the survey design may select points at which observations are to be taken, many responses require some spatial extent for their evaluation. The region around the selected point(s), called a support region, over which a response is evaluated can be of any size and/or configuration so long as any observer can identify that area. Effectively these matters lie in the protocols which define how a response is to be evaluated in the field. The protocols may specify how responses are to be evaluated in the field, or how material should be collected in the field for subsequent evaluation in a laboratory. In the latter case, protocols also need to specify how the laboratory evaluations are intended to proceed.

These protocols must be clear so responses can be evaluated in the same way at different points in time, and by any qualified observers. Otherwise long-term series of comparable data can not be developed. This is the reason that protocol definition was listed as a pressing need before field evaluation should progress any further.

APPENDIX B: RESOURCES UTILIZED

The panel members were supplied with materials before the river trip, gathered insights through organized and informal discussions during the trip, and obtained further materials after the river trip. Although the panel has endeavored to become informed relative to its task, it may still have misunderstandings of some important matters. The panel has based this report on the materials and experiences listed below.

B.1 Materials Received Before the River Trip

1. Anonymous. 1998. Untitled. Background information on the process for coordinating and communicating the Adaptive Management Working Group's information needs, along with list of management objectives (MOs) and information needs (INs). 17 pp.

2. Kearsley, M.J.C., and T.J. Ayers. 1996. The effects of interim flows from Glen Canyon Dam on riparian vegetation in the Colorado River corridor, Grand Canyon National Park, Arizona. Final Report.

3. Kearsley, M.J.C., and T.J. Ayers. 1999. Riparian vegetation responses: Snatching defeat from the jaws of victory and *vice versa*. In "The controlled flood in Grand Canyon," R.H. Webb, et al., eds. Geophysical Monograph 110, American Geophysical Union, pp. 309-327.

4. Melis, T., M. Liszewski, B. Gold, L. Stevens, F.M. Gonzales, R. Lambert, L.D. Garrett, W. Vernieu, and B. Ralston. (undated). Draft prospectus for evaluating GCMRC monitoring protocols for the Colorado River ecosystem.

5. Noss, R., M. Gordon, E. Hoagland, C. Lydeard, P. Mehlhop, and B. Roth. (undated). Report of Kanab Ambersnail review panel on taxonomic, ecological and translocation issues concerning the conservation of *Oxyloma* snails in Arizona and Utah. 13 pp.

6. Phillips, A.M., III, and L. Jackson. 1999. Monitoring Hualapai enthnobotanical resources along the Colorado River, 1998-1999. Final Report.

7. Spence, J.R., C.T. LaRue, N.L. Brown, and J. Muller. 1999. Winter and breeding avifauna monitoring along the Colorado River in Glen and Grand Canyons – The 1998 season. Draft. 27 pp.

8. Spence, J.R., C.T. LaRue, J.R. Muller, and N.L. Brown. 1998. 1997 avian community monitoring along the Colorado River from Lees Ferry to Lake Mead. Draft Final Report. 47 pp.

9. Stevens, L.E., F.R. Protiva, D.M. Kubly, V.J. Meretsky, and J. Petterson. 1997. The ecology of Kanab Ambersnail (Succineidae: Oxyloma haydeni kanabensis Pilsbry, 1948) at Vaseys Paradise, Grand Canyon, Arizona: 1995 Final Report. 34 pp.

10. Webb, R.H., D.L. Wegner, E.D. Andrews, R.A. Valdez, and D.T. Patten. 1999. Downstream effects of Glen Canyon Dam on the Colorado River in Grand Canyon: A review. In "The controlled flood in Grand Canyon," R.H. Webb, et al., eds. Geophysical Monograph 110, American Geophysical Union, pp. 1-21.

11. Wohl, E.E., T.J. Randle, A.D. Howard, P.R. Wilcock, P.D. Komar, W.E. Dietrich, V.R. Baker, M.E. Power, and P.S. Chavez. 1999. Grand Canyon Monitoring and Research Center Protocols Evaluation Program (PEP-SEDS) – "Final Report of the Physical Resources Monitoring Peer Review Panel."

B.2 Information Received During the River Trip

1. Kaplinski, M., J.E. Hazel, Jr., R. Parnell, and M. Manone. 1999. Monitoring fine-sediment storage of the Colorado River ecosystem below Glen Canyon Dam, Arizona. Sand Bar Studies Fact Sheet, Department of Geology, Northern Arizona University.

2. Spence, J.R. 2000. Summary of the 1996-1999 avian monitoring program along the Colorado River from Glen Canyon Dam to upper Lake Mead.

3. Stevens, L. 1999. The Colorado River in Grand Canyon; a comprehensive guide to its natural and human history. Flagstaff, Arizona: Red Lake Books, 6th ed., 115 pp.

4. See Table B.1 for the speakers who briefed the panel.

Table B.1. Speakers who briefed the review panel.

Date	Location	Speaker	Affiliation	Topic
March 4, 2000	GCMRC	Loretta Jackson	Hualapai tribe	Ethnobotanical resources
March 4, 2000	GCMRC	Art Phillips	Hualapai tribe	Ethnobotanical sampling and design
March 4, 2000	GCMRC	Josh Korman	Ecometric Research	Conceptual model
March 6, 2000	Marble Canyon	Matt Kaplinski	Northern Arizona University	Debris fan/eddy/beach complexes
March 6, 2000	Vaseys Paradise (mi. 32)	Jeff Sorenson, Larry Stevens	AZ Dept. of Game and Fish, Wildlands Council	Kanab Ambersnail sampling and design
March 6, 2000		Barbara Ralston	GCMRC	Panel charge
March 7, 2000	Tanner	Linda Jalbert	National Park Service, Grand Canyon NP	Grand Canyon permitting system, minimal tool requirement
March 7, 2000	Vegetation study site (mi. 43.1)	Mike Kearsley, Larry Stevens	Northern Arizona University, Wildlands Council	Vegetation sampling and design
March 7, 2000	Willow Flycatcher site (mi. 51.5)	Matt Johnson	Colorado Plateau Field Station	Willow Flycatcher sampling and design
March 7, 2000	Nankoweap (mi. 52)	Larry Stevens	Wildlands Council	Eagle foraging, stream evolution, cultural resources
March 8, 2000	Cardenas (mi. 71)	John Spence	National Park Service, Glen Canyon NRA	Avifauna sampling and design
March 14, 2000	Gooddings Willow (mi. 209)	Mike Yeatts	Hopi tribe	Ethnobotanical resources
Various	various	Larry Stevens	Wildlands Council	Grand Canyon ecology

Various	various	Matt Kaplinski	Northern Arizona University	Grand Canyon geology/sedimentology

B.3 Materials Obtained after the River Trip

1. Brown, B.T., R. Mesta, L.E. Stevens, and J. Weisheit. 1989. Changes in winter distribution of Bald Eagles along the Colorado River in Grand Canyon, Arizona. Journal of Raptor Research 23: 110-113.

2. Brown, B.T., and L.E. Stevens. 1997. Winter Bald Eagle distribution is inversely correlated with human activity along the Colorado River, Arizona. Journal of Raptor Research 31: 7-10.

3. Brown, B.T., L.E. Stevens, and T.A. Yates. 1998. Influences of fluctuating river flows on Bald Eagle foraging behavior. The Condor 100: 745-748.

4. EMAP (Environmental Monitoring and Assessment Program). 1993. Environmental Monitoring and Assessment Program Master Glossary. EPA/620/R-93/013, Research Triangle Park, NC: U.S. Environmental Protection Agency, Office of Research and Development, Environmental Monitoring and Assessment Program.

5. EPA (U.S. Environmental Protection Agency). 1992. Terms of Environment: Glossary, Abbreviations, and Acronyms. EPA175B92001. Washington, DC: U.S. Environmental Protection Agency, Communications, Education, and Public Affairs.

6. GCMRC. 1997. The Grand Canyon Monitoring and Research Center Long-Term Monitoring and Research Strategic Plan. Final Draft. Obtained from http://www.gcmsc.gov.

7. Merényi, E., W.H. Farrand, L.E. Stevens, T.S. Melis, and K. Chhibber. 2000. Studying the potential for monitoring Colorado River ecosystem resources below Glen Canyon Dam using low-altitude AVIRIS data. Proceedings of the 10th AVIRIS Earth Science and Applications Workshop, Pasadena, CA.

8. National Research Council. (1999). Downstream: Adaptive Management of Glen Canyon Dam and the Colorado River Ecosystem. National Academy Press, Washington, D.C. 12+230 pp.

9. Parnell, R.A., Jr., and J.B. Bennett. 1999. Mineralization of riparian vegetation buried by the 1996 controlled flood. In “The controlled flood in Grand Canyon,” R.H. Webb, et al., eds. Geophysical Monograph 110, American Geophysical Union, pp. 225-239.

10. Peterson, S. A., N. S. Urquhart, and E. B. Welch (1999). Sample representativeness: a must for reliable regional estimates of lake condition. Environmental Science and Technology **33**: 1559-1565.

11. Schmidt, J.C., R.H. Webb, R.A. Valdez, R.R. Marzolf, and L.E. Stevens. 1998. Science and values in river restoration in the Grand Canyon. BioScience 48: 735-747.

12. Stevens, D.L., Jr. 1997. Variable density grid-based sampling designs for continuous spatial populations. Environmetrics 8: 167-195.

13. Stevens, D.L., Jr., and A.R. Olsen. 1999. Spatially restricted surveys over time for aquatic resources. Journal of Agricultural, Biological, and Environmental Statistics 4: 415-428.

14. Stevens, D.L., Jr., and N.S. Urquhart. 2000. Response designs and support regions in sampling continuous domains. Environmetrics 11: 13-41.

15. Stevens, L.E., K.A. Buck, B.T. Brown, and N.C. Kline. 1995. Dam and geomorphological influences on Colorado River waterbird distribution, Grand Canyon, Arizona, USA. Regulated Rivers 13: 151-169.

16. Stevens, L.E., J.C. Schmidt, T.J. Ayers, and B.T. Brown. 1995. Flow regulation, geomorphology, and Colorado River marsh development in the Grand Canyon, Arizona. Ecological Applications 5: 1025-1039.

17. Stevens, L.E., J.P. Shannon, and D.W. Blinn. 1997. Colorado River benthic ecology in Grand Canyon, Arizona, USA: Dam, tributary and geomorphological influences. Regulated Rivers 13: 129-149.

18. Stevens, L.E., J.E. Sublette, and J.P. Shannon. 1998. Chironomidae (Diptera) of the Colorado River, Grand Canyon, Arizona, USA, II: Factors influencing distribution. Great Basin Naturalist 58: 147-155.

19. Urquhart, N.S., S.G. Paulsen, and D.P. Larsen. 1998. Monitoring for policy-relevant regional trends over time. Ecological Applications 8: 246-257.

APPENDIX C: THE PANEL

Gregor T. Auble, a riparian ecologist with the United States Geological Survey at the Midcontinent Ecological Science Center in Fort Collins, CO, received his Ph.D. in ecology from the University of Georgia (1982). He spent a number of years constructing simulation models with the Adaptive Environmental Assessment Group of the U.S. Fish and Wildlife Service; and for the last 10 years has been doing research on responses of western riparian vegetation to flow and sediment alterations.

John G. Blake, associate professor of biology, University of Missouri, Saint Louis, MO (1993 -), received his Ph.D. in avian ecology from the University of Illinois in 1983, where his research focused on the effects of forest fragmentation on bird communities. His current research is on the effects of spatial and temporal variation in resource abundance on the distribution and abundance of tropical birds.

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