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FORUM

Balancing Endangered Species and Ecosystems: A Case Study of Adaptive Management in Grand Canyon

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ABSTRACT / Adaptive ecosystem management seeks to sustain ecosystems while extracting or using natural resources. The goal of endangered species management under the Endangered Species Act is limited to the protection and recovery of designated species, and the act takes precedence over other policies and regulations guiding ecosystem management. We present an example of conflict between endangered species and ecosystem management during the first planned flood on the Colorado River in Grand Canyon in 1996. We discuss the resolution of the conflict and the circumstances that allowed a solution to be reached. We recommend that adaptive management be implemented extensively and early in ecosystem management so that information and working relationships will be available to address conflicts as they arise. Though adaptive management is not a panacea, it offers the best opportunity for balanced solutions to competing management goals.

Ecosystem management is a process of balancing physical, biological, and sociological aspects of managed landscapes (Grumbine 1994). In contrast, endangered species management under the Endangered Species Act is a narrowly focused discipline in which most other management needs are intentionally subordinated to the needs of endangered species by the language of the act. The presence of endangered species can therefore limit options for ecosystem managers, and conflicts may arise between the safest course of action for endangered species and the preferred course of action for the ecosystem in which endangered species are found. We present a case study of successful integration of ecosystem and endangered species management—protection of the endangered Kanab ambersnail (*Oxyloma haydeni kanabensis*) and its habitat during the first controlled flood of the Grand Canyon using Glen Canyon Dam (Wegner 1996). Grand Canyon ecosystems were significantly affected by construction of Glen Canyon Dam; this adaptive management experiment was used to study the effectiveness of using high-volume controlled releases from the dam to simulate effects of natural flooding on the downstream ecosystem. We discuss the adaptive management environment in which this integration occurred, as well as other factors that contributed to the speed and success of the outcome.

KEY WORDS: Ecosystem management; Planned flood; Kanab ambersnail; *Oxyloma haydeni kanabensis;* Endangered species; Adaptive management

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Historical Approaches to Dam Management

Historically, many western dams were constructed to provide flood protection, water, and electricity to rural and urban communities at low cost. Most dams in the western United States were built prior to the passage of environmental and water quality laws; little thought was given to the consequences of dam-related disruptions of natural ecological processes (Harper and Ferguson 1995, Philip 1995). In fact, some side effects of dams (e.g., reservoir recreation, increased downstream water clarity, improved conditions for exotic game fish) may be viewed as environmental improvements (Morgan and others 1991, Jackson 1995, Stevens and Wegner 1995, Stevens and others 1997). Only recently has conservation of predam ecosystem components (e.g., biological diversity, hydrological regimes) and ecosystem integrity been added to the list of concerns potentially governing dam management (Gore and Petts 1989, Stanford and others 1996).

Traditional approaches to dam management primarily seek to create a predictable, reliable water supply so that resource managers and users may make long-term commitments to improve social conditions and efficiency of resource delivery. However, experience increasingly demonstrates that attempts to control natural resources do not reduce variability in resource availability, but rather increase it (Holling 1986, Holling and Meffe 1996). In addition, so-called command-and-control management may reduce the range of services offered by ecosystems and damage physical and economic structures related to the resource. By seeking to control natural resources without understanding the implications of our actions, we lose the opportunity to understand and protect the systems we affect (Nash 1989). Though innovation carries with it the risk of failure, new approaches are needed to reduce human impacts on managed ecosystems.

Adaptive Management

Adaptive management was suggested in the late 1970s in response to the increasing complexity of environmental management problems (Holling 1978). It is a technique for coupling science and management so that each responds to the needs and information of the other. Neither undertaking is consistently subordinated; rather, each has areas of high priority. Scientific research is focused on those areas of greatest importance to managers, while management activities are assessed by a wide range of stakeholders and planned and monitored as a series of ongoing experiments.

A central tenet of adaptive management is that management activities affect ecosystems and constitute experiments whether data are collected or not (Walters 1986). Acknowledging this, decisions instituted under adaptive management are based on the results of inventory, monitoring, and research activities—learning and managing by designed experiments. Implicit in adaptive management is the recognition that resource management must consider the needs of all affected parties, which cannot be determined on the basis of discussion alone but requires accurate information on the managed resources and the ecosystems in which they are embedded.

Since the introduction of adaptive management, several authors have noted the social, political, economic, and psychological obstacles to its implementation (Blumm and Simrin 1991, Halbert 1993, Lee 1993, Gunderson and others 1995, McLain and Lee 1996, Walters 1997, Rogers 1998). These obstacles are substantial, as evidenced by the number of natural resource management systems that do not use adaptive management. Nevertheless, for large landscape units where many goals must be addressed simultaneously by several different administrative entities, adaptive management appears to provide the best hope of success (Lee 1993).

Adaptive Management at Glen Canyon Dam

Glen Canyon Dam is one of the key regulatory structures on the Colorado River system; it is managed by the Bureau of Reclamation (BR). In 1982 the Glen Canyon Environmental Studies, a Department of Interior research program, was initiated to explore the impacts of dam operations on downstream ecological resources (Table 1). An important conclusion developed from the Glen Canyon Environmental Studies program was that the river ecosystem in Grand Canyon had evolved in a highly variable environment, which was significantly altered by Glen Canyon Dam. The Environmental Impact Statement (EIS) on the operations of Glen Canyon Dam concluded that traditional methods of dam management were inadequate to compensate for the magnitude of environmental impacts to the Colorado River ecosystem (Bureau of Reclamation 1995). An adaptive management program was recommended as an approach that would permit information on the condition of the river ecosystem to guide decisions concerning dam operations (Weiringa and Morton 1996). When the Record of Decision on the EIS was signed in 1996, this recommendation became administratively binding. Similar recommendations for adaptive management were made by Congress in the Grand Canyon Protection Act of 1992.

Research and monitoring systems for Grand Canyon were initiated under Glen Canyon Environmental Studies, and are being revised by the Grand Canyon Monitoring and Research Center (currently administered by the Bureau of Reclamation for the Department of the Interior). A federal advisory committee, the Adaptive Management Work Group, composed of 27 state, federal, tribal, and public representatives, was formed late in 1997 with a Technical Work Group designated to provide relevant technical information (Department of Interior 1997).

The first large-scale exercise in adaptive management planned for Grand Canyon was an experimental flood using releases from Glen Canyon Dam to mimic floods that occurred annually before the dam was built. Initially, planners anticipated no impact or benefits to most species of special concern in the river corridor. However, predicted damage to terrestrial habitat of the Kanab ambersnail (Bureau of Reclamation 1996) brought endangered species management into conflict with adaptive ecosystem management and had the potential to prevent the planned flood (Fish and Wildlife Service 1994, 1996). Minor concerns also arose concerning damage to habitat of the endangered south-

Table 1. A brief legislative and administrative history of Glen Canyon Dam

1956	Colorado River Storage Project Act—authorizes, among other things, construction of Glen Canyon Dam.
1963–1980	Glen Canyon Dam closed, Lake Powell Reservoir fills.
1974	Suit filed against Department of Interior to prevent extreme fluctuations in water level. District court ruled and appeals court upheld that there would be no interference in the operations of the dam until Bureau of Reclamation had considered the possibility that operations of the dam might require an impact statement under the National Environmental Policy Act (NEPA).
1983	Letter from Bureau of Reclamation commissioner outlines the original objectives of the Glen Canyon Environmental Studies (GCES)—to determine how operations of Glen Canyon Dam affected the downstream environment and associated recreation.
1987	Planned changes in dam operations resulting from increased generator capacity require an environmental assessment under NEPA.
1988	Department of Interior directs that an environmental impact statement be prepared to assess the environmental impacts of Glen Canyon Dam operations.
1994	Draft environmental impact statement issued. FWS responds with a Biological Opinion that includes permissible levels of harm to Kanab ambersnail.
1995	Controlled flood formally proposes, GCES prepares environmental assessment.
1995	U.S. Fish and Wildlife Service issues a Biological Opinion in response to the environmental assessment, indicating that the proposed flood will put endangered species in jeopardy, and listing reasonable and prudent measures to be taken to mitigate harm to these species.
Mar 1996	Reconsultation on reasonable and prudent measures described in this paper.
Mar–Apr 1996	Controlled flood released from Glen Canyon Dam.
Oct 1996	Glen Canyon Dam environmental impact statement finalized by signing of Record of Decision.

western willow flycatcher (*Empidonax traillii extimus*) and several other rare but unlisted species, but these did not have the potential to prevent the flood and are not discussed here (see Stevens and others 2000).

Kanab Ambersnail (KAS)

KAS is a terrestrial snail first discovered at Vasey's Paradise in Arizona's Grand Canyon in 1991 (Spamer and Bogan 1993). Previously known from two sites in southern Utah and believed to have been extirpated from one of those, it was listed as endangered in 1992 on the basis of the small number of known populations. Vasey's Paradise is the only protected location because it occurs within Grand Canyon National Park, where federal land managers must fully protect endangered species. The remaining Utah population occurs on privately owned land.

Vasey's Paradise, 50 km downstream from Lee's Ferry, is a small (<0.25 ha) patch of riparian vegetation associated with a limestone spring that issues from the canyon wall 100 m above the Colorado River. The lush vegetation serves as habitat for KAS. Prior to closure of Glen Canyon Dam in 1963, photos show that spring flooding scoured vegetation back, controlling the lower limit of habitat. After dam closure halted annual flooding, vegetation cover increased by approximately 40% down to the lower water level associated with dam operations (KAIMG 1997).

In 1994, in response to the endangered species listing, a KAS Working Group was organized, composed of members of the Arizona Game and Fish Department, the Glen Canyon Environmental Studies, the U.S. Fish and Wildlife Service (FWS), and the National Park Service. Results of research in 1995 provided a March (pre–breeding season) population estimate of approximately 18,500 snails and a September (post–breeding season) estimate of approximately 100,000 snails (KAS have an approximately 1-yr lifespan).

Following release of the 1994 draft EIS on operations of Glen Canyon Dam, FWS issued a Biological Opinion (1994) on the effects of dam operations on endangered species, including KAS. The opinion set a permissible level of impact on KAS habitat below which BR could operate Glen Canyon Dam without additional consultation. According to the opinion, if flows from Glen Canyon Dam resulted in the destruction of more than 10% of occupied habitat, BR was required to consult with FWS and cease the operations causing habitat damage until consultation was complete.

The Experimental Flood—Spring 1996

The experimental flood from Glen Canyon Dam was designed to serve as an experiment under adaptive management, permitting researchers to determine ecosystem responses to a specific management action. Hypotheses for the flood experiment dealt with many aspects riverine and riparian processes (Hazel and others 1999, Patten and others 2000, Rubin and others 1998, Schmidt and others 2000, Stevens and others 2000). The flood regime was designed to mobilize sediments from the channel bottom and deposit them on bars and beaches to restore eroded shoreline habitats, as predam floods had done. In addition, planners hoped that other effects of predam floods might be achieved, for example, that the flood would deepen backwaters and eddies used by native fish and scour marsh vegetation from return to current channels. The experiment also offered an opportunity to improve models of sediment transport, water movement, nutrient flows, and other ecosystem processes, enabling managers to better predict results of dam operations.

Scientists planning the flood were directed by FWS and Department of Interior to minimize effects of the experimental flood on endangered species. No single flood-flow regime gave optimal results for all endangered species and for the ecosystem as a whole. Therefore, proposed releases were balanced between two management issues: (1) maximize ecosystem benefits throughout Grand Canyon, and (2) minimize impacts to endangered species and their habitats.

Conflict Between the Experimental Flood and KAS

In its environmental assessment of the experimental flood, BR (1996) predicted that as much as 17% of KAS habitat might be destroyed—7% more than allowed by the 1994 FWS Biological Opinion on operations of Glen Canyon Dam. The prediction was based on results of a model designed to predict river elevation at known dam discharges (Randle and Pemberton 1988). The model error range was $\pm$46 cm ($\pm$1.5 ft), and the Environmental Assessment cited the worst-case water level—estimate plus 46 cm—to determine potential habitat destruction.

BR entered into formal consultation with FWS to determine whether the experimental flood could proceed despite the predicted level of take of KAS habitat. Acknowledging the overall benefits of the flood while stressing the need to protect KAS, FWS developed reasonable and prudent measures to mitigate impacts to KAS, requiring that 90% of snails in the area below the worst-case high water line be relocated above that line (FWS 1996). FWS further required that BR monitor the site to ascertain the actual level of take and continue monitoring for a year after the flood to determine KAS population and habitat recovery. The KAS Working Group advised BR that these were feasible, conservative measures, given available population estimates. Due to the short time line for experimental flood planning (November 1995–March 1996), FWS requirements were framed quickly, during the period of KAS winter dormancy.

Thus, for KAS, the major experimental aspects of the planned flood involved the model predictions of water level during the flood, the impact of flood waters on KAS habitat, and the impact of habitat loss on KAS population levels. With a single KAS population on a single river, and a single flood, full employment of replicates and controls was not possible (see Walters and Green 1997). Nevertheless, the purposeful collection of preflood baseline information and postflood monitoring data permitted us to maximize learning during the experiment.

KAS Working Group members arrived at Vasey's Paradise 8 days before the beginning of the experimental flood, in time to complete the assigned tasks, but as late as possible to ensure that a large portion of the KAS population would be active and readily located. Nevertheless, many KAS were still dormant when researchers arrived, on soil and in litter under as much as a meter of living vegetation. On-site estimates of KAS population size were substantially larger than counts from the previous fall had suggested, probably due to the exceptionally mild 1995–1996 winter.

Finding and removing active snails required damaging but not destroying much of the vegetation below the worst-case flood line. However, finding and removing dormant snails required removing all vegetation and the associated rootmat in which the snails lay dormant. Therefore, FWS reasonable and prudent measures required researchers to destroy 90% of vegetation associated with the worst-case estimate, even though flood waters might not rise to worst-case levels. Although this was most conservative for preserving snails, it was not conservative of habitat. In addition, destroying 90% of habitat in the potential flood zone would prevent researchers from leaving patches of vegetation to determine the ability of plant species to withstand the force of the flood, an experiment we felt needed to be conducted. These concerns were relayed from the field to BR, which requested immediate reconsultation with FWS on the reasonable and prudent measures.

Reworking the Balance

The FWS biologist charged with writing the mitigation requirements was flown to Vasey's Paradise to confer with Working Group members in the field 4 days before the commencement of the experimental flood. The researchers explained that KAS numbers were higher than anticipated, and that the present reasonable and prudent measures required the destruction of vegetation that might not be affected by the experimental flood and prevented experimentation to determine the impact of flood waters on vegetation.

The following day, FWS issued amended the reasonable and prudent measures, directing that 75% of snails be relocated from 50% of the worst-case inundation zone; monitoring requirements were not changed. This modification preserved the approximate number of snails to be moved at the level anticipated using the earlier population estimate. In addition, the change gave the Working Group latitude to leave habitat in the error zone above the predicted flood elevation and to leave small amounts of vegetation below the anticipated flood elevation. As a further experiment, some areas near the anticipated flood elevation were clipped to the level of the root mat to determine if this treatment would improve the persistence of roots and soil during the experimental flood and hasten habitat recovery.

The Working Group was successful in meeting the revised reasonable and prudent measures. Flood waters rose only to the estimated level, sparing vegetation in the error zone, which would have been destroyed by researchers under the original measures. However, as anticipated, over 95% of primary habitat below the inundation line was lost (KAIMG 1997, Stevens and others 1999). Plant species important to KAS showed essentially no ability to persist during flood flows, and clipping stems provided little protection from scour. The Working Group estimates it will take several years for all KAS habitat to recover to preflood levels, although some host plant species are recovering more quickly.

The spring season following the experimental flood (spring 1996) was mild, and KAS had an extended breeding period with two peaks of reproduction before fall, a phenomenon not previously reported for the genus (one cycle is considered usual). The KAS population is not presently considered to be at greater risk as a result of the experimental flood; estimated population sizes returned to preflood levels in 1997 (Steven and others 2000). The flood impacts on KAS habitat were considerable, but they did not jeopardize the population.

Effective Adaptive Management

The experimental flood, an undertaking involving several hundred kilometers of river and nearly as many researchers, demonstrated a commitment to ecosystem adaptive management and research and a recognition of the value of science to improving resource management (Vaselaar 1997). This was the first use of releases from a major dam as an experimental tool for ecosystem research. Conservation requirements for KAS might have precluded the experiment. The interplay between researchers, BR, and FWS in the days before the experimental flood was a further example of what is possible in systems where adaptive management is practiced. When new information became available from the field, it was rapidly communicated to managers, outside consultation was requested, and the resulting changes in mitigation were effected, all within 72 h, allowing the experiment to proceed on schedule. Several factors improved the integration of endangered species and ecosystem management in this case.

Established Monitoring Team and Protocols

The KAS Working Group was established 2 yr before the experimental flood was conducted, and had been monitoring the KAS population at Vasey's Paradise for more than a year in anticipation of potential, planned flood impacts. KAS population information suggested that the KAS population would be at a seasonal low during the experimental flood, so that fewer snails would need to be relocated. In addition, existing topographic surveys of snail habitat and existing stage-discharge models permitted accurate prediction of the amount of habitat to be inundated and potentially destroyed. Long-term monitoring and research that addresses management information needs are two of the foundations of adaptive management, and their role in predicting and assessing impacts of management activities was clearly demonstrated here.

The early establishment of the KAS Working Group meant that the team of researchers undertaking research and mitigation work during the flood was experienced with the site, the species, and the research protocols. The team worked quickly and efficiently together and discussed problems cogently as they arose. All agencies with an interest in the KAS population were represented. Only the FWS biologist charged with writing the reasonable and prudent measures could not be in the field during the flood, and she was able to travel to review the situation in order to revise the measures.

Universal Recognition of Experimental Flood Value

The agencies associated with the KAS Working Group all agreed that the experimental flood was likely to benefit the Grand Canyon ecosystem. The flood had the potential to improve habitat for humpback chub (*Gila cypha*), another endangered species in Grand Canyon. This common understanding and approval improved chances for conservative compromise, and allowed Working Group members to share ideas without concerns about conflicting agency agendas.

Trade-Offs Between Endangered Species Management and Adaptive Management

KAS was listed under the ESA because only two populations were known to exist. The Vasey's Paradise population is relatively large for an endangered species (larger than 10,000 individuals throughout the 1995 growing season), and FWS was able to allow the loss of some individuals without abrogating their responsibilities under the ESA. For this reason, vegetation in the error zone could be saved despite the worst-case possibility that snails in that vegetation would be lost. The Working Group was able to reduce potential losses by relocating some active snails from the error zone without damaging vegetation. Such trade-offs are not always available, nor are remedies always so inexpensive. Moving the snails out of harm's way required no expensive technology and only reasonable amounts of time. Assessing habitat extent, and calculating the possible trade-off required quick, efficient work, but no heroic efforts.

While the experimental flood was administratively approved, the endangered status of KAS still reduced experimental options under adaptive management. Flood levels that would have removed substantially more KAS habitat were not considered, and no areas of vegetation at Vasey's Paradise were set aside as controls because the extreme likelihood of loss of all snails in inundated habitat was considered unacceptable.

Conclusion/Implications

Endangered Species versus Ecosystems

There will always be species whose fates are so precarious that their needs outweigh all but the most urgent competing demands. In such instances, individual animals are extremely valuable. However, when populations, rather than individuals, are rare, the fate of individual animals is less critical and management actions that risk individuals but no populations are more tenable (Rabinowitz and others 1986).

The ESA, which plays an invaluable role in protecting endangered species, uses an approach which is strongly protective of individuals, regardless of the kind of rarity involved. Under the ESA, FWS provides comments on endangered species impacts to agencies planning ecosystem management activities. The individual-based focus on the act leaves FWS without strong legal support when acquiescing to ecosystem management that may risk individuals of listed species. Recognition of the different ways in which species can be considered rare (Rabinowitz and others 1986) and the implications of these differences to managers would allow FWS more latitude in crafting responsible compromises. In addition, recognition of the usefulness of ecosystem management as a strategy to reduce future listings would permit FWS to balance the possible overall achievements of ecosystem management against the potential harm to individuals listed species. In future revisions of the ESA, these issues may expand the range of management options.

Applying Adaptive Management

Adaptive management is neither a panacea nor a means to escape difficult management decisions. In fact, by requiring constant, timely interchange among researchers, resource managers, and other stakeholders, adaptive management has the potential to increase the number of difficult management decisions by revealing new problems and new possibilities more rapidly. However, the same mechanisms can also permit rapid resolution of problems and increased protection of natural resources (Walters and Holling 1990, Holling 1995).

At Glen Canyon Dam, adaptive management has the potential to establish a new paradigm for Colorado River management and provide a template for dam management in other river systems. The success of the first planned flood has led to additional research flood planning in Grand Canyon and at Flaming Gorge Dam on the Green River, a tributary of the Colorado. The future has promise, but one experimental flood, however well received and well publicized, does not constitute a trend or a long-term solution to dam impacts.

The identification of stakeholders during adaptive management often increases the number of affected parties, each with its own values and preferred outcomes. The Adaptive Management Working Group for Glen Canyon Dam at the end of 1998 includes 27 stakeholder groups, few of whom are represented by practicing scientists. Researchers are accustomed to taking a peripheral role in management arenas, such as the one governing Glen Canyon Dam, and few pursue research in order to participate in the politics common to such arenas. Furthermore, scientists are explicitly trained against advocacy other than advocacy of improved scientific methodology. This reticence is not shared by the other stakeholders (power users, water users, recreational users, Native American tribes, environmental advocates) who comment actively on dam operations or by the managers who now operate the dam with considerable outside advice.

Increasingly, stakeholders may employ scientists, and this is one route by which science can become a tool, rather than a point of view, in adaptive management (e.g., Lee 1993). A broader use of science is desirable. Scientists have their own values and biases. They may overemphasize the model building and testing aspects of adaptive management (Walters 1997) are often uncomfortable with or ignorant of information learned without formal experimentation, and may prematurely discount views of other stakeholders who do use such information (McLain and Lee 1996). More varied links between stakeholders and researchers should improve use of all kinds of information.

Nevertheless, scientists themselves will remain the group most familiar with the data, and most sensitive to its shortcomings and strengths. Scientists can and should be advocates for the application of sound science in adaptive management. Their advocacy will not lead to uniformity of opinion; rather, it will fairly demonstrate the range of conclusions that can be reached from the data and identify a range of options that can be further refined in the social and managerial arenas into the next round of adaptive management experiments.

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Literature Cited

Blumm, M. C., and A. Simrin. 1991. The unraveling of the parity promise: hydropower, salmon and endangered species in the Columbia Basin. *Environmental Law* 21:67–744.

Bureau of Reclamation. 1995. Operation of Glen Canyon Dam: final environmental impact statement. Bureau of Reclamation, Salt Lake City, UT.

Bureau of Reclamation. 1996. Environmental assessment on the experimental flood: Glen Canyon Dam. Bureau of Reclamation, Salt Lake City, UT.

Department of Interior. 1997. Charter of the Adaptive Management Work Group: establishment of a federal advisory committee to advice the Secretary of the Interior on the impacts of Glen Canyon Dam operations. U.S. Department of Interior.

Fish and Wildlife Service. 1994. Final biological opinion: operation of Glen Canyon Dam as the modified low fluctuating flow alternative of the final environmental impact statement, #2-21-93-F-167. Phoenix, AZ.

Fish and Wildlife Service. 1996. Biological and conference opinions on operation of Glen Canyon Dam—controlled release for habitat and beach building. Phoenix, AZ.

Gore, J. A., and G. E. Petts (eds.). 1989. Alternatives in regulated river management. CRC Press, Boca Raton, FL.

Grumbine, R. E. 1994. What is ecosystem management? *Conservation Biology* 8:27–38.

Gunderson, L. H., C. S. Holling, and S. S. Light. 1995. Barriers and bridges to the renewal of ecosystems and institutions. Columbia University Press, NY, 593 pp.

Halbert, C. L. 1993. How adaptive is adaptive management? Implementing adaptive management in Washington State and British Columbia. *Reviews in Fish Biology and Fisheries* 1:261–283.

Harper, D. M., and A. J. D. Ferguson (eds.). 1995. The ecological basis for river management. John Wiley and Sons, West Sussex, England, 614 pp.

Hazel, J. E., Jr., M. A. Kaplinski, R. A. Parnell, Jr., M. Manone, and A. Dale. 1999. Topographic and bathymetric changes at thirty-three long-term study sites, *In* R. H. Webb, J. S. Schmidt, G. R. Marzolf, and R. A. Valdez (eds.), The controlled flood in Grand Canyon. AGU Geophysical Monograph 110.

Holling, C. S. (ed.). 1978. Adaptive environmental assessment and management. John Wiley and Sons, NY, 454 pp.

Holling, C. S. 1986. Resilience of ecosystems; local surprise and global change. Pages 292–317 *in* W. C. Clark and R. E. Munn (eds.), Sustainable development of the biosphere. Cambridge University Press, Cambridge.

Holling, C. S. 1995. What barriers? What bridges? Pages 3–36 *in* L. H. Gunderson, C. S. Holling, and S. S. Light (eds.), Barriers and bridges to the renewal of ecosystems and institutions. Columbia University Press, NY.

Holling, C. S., and G. K. Meffe. 1996. Command and control and the pathology of natural resource management. *Conservation Biology* 10:328–337.

Jackson, D. C. 1995. Distribution and stock structure of blue catfish and channel catfish in macrohabitats along riverine sections of the Tennessee-Tombigbee waterway. *North American Journal of Fisheries Management* 15:845–853.

KAIMG (Kanab Ambersnail Interagency Monitoring Group). 1997. The impacts of an experimental flood from Glen Canyon Dam on the endangered Kanab ambersnail at Vaseys Paradise, Grand Canyon, Arizona. Report to Grand Canyon Monitoring and Research Center, Flagstaff, AZ.

Lee, K. N. 1993. Compass and gyroscope: integrating science and politics for the environment. Island Press, Washington, DC, 243 pp.

McLain, R. J., and R. G. Lee. 1996. Adaptive management: promises and pitfalls. *Environmental Management* 20:437–448.

Morgan, R. P., II, R. E. Jacobsen, S. B. Weisberg, L. A. McDowell, and H. T. Wilson. 1991. Effects of flow alteration on benthic macroinvertebrate communities below the Brighton Hydroelectric Dam. *Journal of Freshwater Ecology* 6:419–430.

Nash, R. F. 1989. Rights of nature: a history of environmental ethics. University of Wisconsin Press, Madison, WI, 290 pp.

Patten, D. T., D. A. Harpmann, M. I. Voita, and T. J. Randle. 2000. A managed flood on the Colorado River: background, design and implementation. *Ecological Applications* (submitted).

Philip, F. L. 1995. A river no more: the Colorado River and the west, rev. and exp. ed. University of California Press, 372 pp.

Rabinowitz, D., S. Cairns, and T. Dillon. 1986. Seven forms of rarity and their frequency in the flora of the British Isles. Pages 182–204 *in* M. E. Soulé (ed.), Conservation biology: the science of scarcity and diversity. Sinauer Associates, Inc., Sunderland, MA.

Randle, T. J., and E. L. Pemberton. 1988. Results and analysis of STARS modeling efforts of the Colorado River in Grand Canyon. National Technical Information Services Report PB88183421/AS.

Rogers, K. 1998. Managing science/management partnerships: a challenge of adaptive management. Conservation Ecology [online] 2(2):R1. http://222.consecol.org/vol2/iss2/resp1.

Rubin, D. M., J. M. Nelson, and D. J. Topping. 1998. Relation of inversely graded deposits to suspended-sediment grain-size evolution during the 1996 flood experiment in Grand Canyon. *Geology* 26:99–102.

Schmidt, J. C., P. E. Grams, J. E. Hazel, and M. Kaplinski. 2000. The effectiveness of the 1996 beach/habitat building flow in restoring the physical environment of the Colorado River corridor in Grand Canyon. *Ecological Applications* (submitted).

Spamer, E. E., and A. E. Bogan. 1993. Mollusca of the Grand Canyon and vicinity, Arizona: new and revised data on diversity and distributions, with notes on Pleistocene-Holocene mollusks of the Grand Canyon. *Proceedings of the Academy of Natural Sciences of Philadelphia* 144:21–68.

Stanford, J. A., J. V. Ward, W. J. Liss, C. A. Frissell, R. N. Williams, J. A. Lichatowich, and C. C. Coutant. 1996. A general protocol for restoration of regulated rivers. *Regulated Rivers* 12:391–413.

Stevens, L. E., and D. L. Wegner. 1995. Changes on the Colorado River: operating Glen Canyon Dam for environmental criteria. Pages 65–74 *in* Northeastern Illinois Planning Commission (ed.), Using ecological restoration to meet Clean Water Act goals: proceedings of a national symposium. Northeastern Illinois Planning Commission, Chicago, IL.

Stevens, L. E., T. J. Ayers, J. B. Bennett, K. Christiansen, M. J. C. Kearsley, V. J. Meretsky, A. M. Phillips, III, R. A. Parnell, J. Spence, M. K. Sogge, A. E. Springer, and D. L. Wegner. 2000. Planned flooding and riparian trade-offs: the regulated Colorado River Corridor in Grand Canyon. *Ecological Applications* (submitted).

Stevens, L. E., K. A. Buck, B. T. Brown, and N. C. Kline. 1997. Dam and geomorphological influences on Colorado River waterbird distribution, Grand Canyon, Arizona, USA. *Regulated Rivers* 13:151–169.

Vaselaar, R. T. 1997. Opening the flood gates: the 1996 Glen Canyon Dam experiment. *Restoration and Management Notes* 15:119–125.

Walters, C. J. 1986. Adaptive management of renewable resources. McMillan Publishing Co., NY, 374 pp.

Walters, C. J. 1997. Challenges in adaptive management of riparian and coastal ecosystems. Conservation Ecology [online] 1(2):1. http://222.consecol.org/vol1/iss2/art1.

Walters, C. J., and R. Green. 1997. Valuation of experimental management options for ecological systems. *Journal of Wildlife Management* 61:987–1006.

Walters, C. J., and C. S. Holling. 1990. Large-scale management experiments and learning by doing. *Ecology* 71:2060–2068.

Wegner, D. L. 1996. Faking the flood: scientists experiment with floodlike releases to restore habitat below Glen Canyon Dam. *World Rivers Review* 12:10–11.

Weiringa, M. J., and A. G. Morton. 1996. Hydropower, adaptive management, and biodiversity. *Environmental Management* 20:831–840.