A Special Section on Dam Removal and River Restoration

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Human activities have degraded many of the world's ecosystems, which has created an urgent need for strategies that can restore their ecological integrity. This need is accompanied by many scientific challenges, however. In particular, ecosystems are among the most complex entities in the hierarchy of life, and the successful repair of damaged systems will require a deep understanding of the processes that determine their structure and function. Biologists have a critical role to play in creating this knowledge because of their expertise in such varied phenomena as the role of microbes in detoxifying anthropogenic contaminants, the effects of disturbance on population persistence, and the factors influencing competitive interactions between native and exotic species.

By itself, however, biological knowledge is not sufficient for restoring degraded ecosystems. Two other types of expertise are also needed for developing integrated restoration solutions. First, because ecosystems are composed of many interacting abiotic and biotic components, biologists must collaborate with their colleagues in the physical sciences to learn how these systems work. Second, because humans are such strong interactors in these complex systems, we need to work with experts who can help us understand how human attitudes, institutions, and technologies influence the condition and management of ecosystems. Such enhanced interdisciplinary dialogue and unified approaches are essential for creating public policies that can sustain the planet's life support systems (Lubchenco 1998, Covich 2000, Ludwig et al. 2001).

Proposals to restore rivers via dam removal raise many issues that require broad discussion and teamwork. This approach to river restoration derives from the growing recognition that dams often disrupt the structure and function of river ecosystems by modifying flow regimes, disrupting sediment transport, altering water quality, and severing their biological continuity (Ward and Stanford 1979, Petts 1984, Collier et al. 1996). Future dam removal decisions can be enhanced by developing a more complete scientific understanding of the processes that determine how rivers are affected by different types of dams and how they respond to dam removal. There is an equally important need to understand the social, economic, engineering, and legal factors that influence dam removal decisions. Assembling a diverse array of experts to explore these different facets of dam removal was an exciting challenge for us. Listening to and participating in the dialogue that took place when those experts gathered at the annual meeting of the Ecological Society of America in August 2001 was even more rewarding.

This special section of *BioScience* brings together those diverse authorities, and a few others, to examine the potential utility of dam removal as a method of river restoration. Our goal is not just to explore the many different scientific and social aspects of this topic but also to consider how these components can and should be connected. Bruce Babbitt, former secretary of the US Department of the Interior during the Clinton administration, is intimately familiar with the subject matter, having been present—sledgehammer in hand—at many dam removals across the United States. His passionate essay (Babbitt 2002) clearly frames both the scientific and human dimensions of the subject. In particular, he emphasizes the critical need for strong science, not just to predict what will happen when dams are removed but also to monitor dam removal outcomes so that we learn how to maximize the effectiveness of this restoration method.

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The next six articles focus on various scientific facets of dam removal and river restoration. Poff and Hart (2002) provide an overview of the ways in which dams impair river ecosystems, and they highlight the conceptual and data needs for creating a more systematic and robust science of dam removal. They quantify variation in such important dam characteristics as size and operation at a national scale and describe how this variation can form the basis of an ecological classification system that distinguishes the environmental effects of different dam types. Hart and colleagues (2002) review alternative methods for predicting ecological responses to dam removal, emphasizing that knowledge of dam effects and removal responses is far from complete. They develop and have begun to implement an ecological risk assessment framework for determining how potential effects of dam removal vary as a function of dam and river attributes.

Dam removal can cause dramatic changes in fluvial processes and channel morphology, which will in turn affect many other ecosystem components. Pizzuto (2002) examines the challenges involved in predicting the effects of dam removal on sediment transport and channel evolution; he also suggests a range of studies (including collaborations between geomorphologists, engineers, and ecologists) that could lead to improved forecasting. One example of the benefits of such collaboration is the work by Stanley and Doyle (2002), which examines links between geomorphic processes and nutrient dynamics. They describe how nutrient cycling is influenced by various impoundment processes (e.g., sedimentation, denitrification) and show how geomorphic models can help predict changes in nutrient retention after dam removal.

The removal of very large (> 30 meters high) dams has been proposed as a method for restoring endangered anadromous salmon in the Pacific Northwest, but no dams of this size have yet been removed in the United States. Gregory and colleagues (2002) focus particular attention on the complex web of direct and indirect pathways by which large dams modify ecological interactions in major rivers. They illustrate many of the scientific uncertainties associated with large dam removal through case studies of dams in the Elwha and Snake Rivers, and they explore various options for making prudent decisions in the face of such uncertainty. The removal of dams affects not only aquatic biota, but also the riparian habitats associated with river margins and floodplains. Shafroth and colleagues (2002) examine how riparian vegetation is likely to respond to various geomorphic and hydrologic changes stemming from dam removal; they also discuss how sediment management and vegetation planting strategies can be used to enhance restoration outcomes.

The final three articles focus on the economic, social, and legal dimensions of dam removal. Cost-benefit analysis has been proposed as an important economic tool for evaluating the potential consequences of dam removal. Whitelaw and MacMullan (2002) present a conceptual framework for estimating the costs and benefits of dam removal and examine the way such analyses have been performed for dams on the Lower Snake River. They argue for a balanced approach to cost-benefit analysis, one that accounts for all subsidies and externalities and places both costs and benefits in a realistic economic context.

Economic issues are not necessarily the primary determinant of stakeholder attitudes and behaviors regarding dam removal, however. For example, Johnson and Graber (2002) have found that communities are often reluctant to consider the removal of old and obsolete dams, even when removal costs much less than dam repair. They describe some of the social and psychological barriers that prevent individuals and communities from considering dam removal as an option and propose creative methods (e.g., community-based social marketing, diffusion of innovations) for encouraging the adoption of management practices that can restore river ecosystems.

Environmental laws might also be expected to provide a powerful tool for removing dams that impair river ecosystems, but Bowman (2002) shows how laws designed to protect ecosystems can actually be an impediment to ecological restoration. Specifically, environmental laws are often designed to protect the environment by maintaining the status quo (i.e., by preventing degradation), which can inadvertently discourage restoration activities because they also cause a deviation (albeit positive) from the status quo. Bowman suggests that regulatory modifications within existing laws might provide decisionmakers with greater flexibility to approve projects with restoration objectives, although she emphasizes that project outcomes must be assessed carefully to avoid creating loopholes that result in environmental degradation.

Ultimately, the benefits of this collection of articles may be twofold. First, we hope that it succeeds in calling attention to the potential utility of dam removal in restoring rivers and in focusing research on specific scientific, engineering, and socioeconomic questions that can enhance the effectiveness of this innovative restoration method. Second, it may highlight the need for greater dialogue and closer interaction among a diverse array of experts and stakeholders. Many environmental problems would benefit from broader discourse about the best ways to create sound environmental policies, effective management practices, and adaptive institutions that can restore and protect the ecosystems on which all life depends.

Acknowledgments

We thank the authors for their dedication and enthusiasm, Matt Greenstone for his broad perspective and unflagging optimism, and Robin Davis for capable editorial assistance. We are also grateful to the Aquatic Section of the Ecological Society of America and its officers (Steve Kohler, Craig Osenberg, and Margaret Palmer) for sponsoring our symposium ("Dam removal and river restoration: Linking scientific, socioeconomic, and legal perspectives") at the 2001 annual meeting of the Ecological Society of America. The Pew Charitable Trusts provided support to help participants attend the symposium and prepare manuscripts for publication.

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