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Bridging engineering, ecological, and geomorphic science to enhance riverine restoration: local and national efforts

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Abstract. Streams and rivers have experienced some of the most dramatic human-induced alterations of any ecosystem types. Species extinctions and declining water quality and quantity are of such urgent concern that restoration efforts are now a major focus. We argue that successful restoration of running-water ecosystems is best accomplished by a shift from a strict engineering focus to efforts directed by interdisciplinary teams of engineers, ecologists, and geomorphologists. Stream structure and function from a flow, sediment, or biological perspective are inextricably linked to channel dynamics and sediment movement, so geomorphologists have unique contributions to make. Ecologists provide critical input relative to the interplay between on-site ecological processes and the hydrologic and geomorphic context in which these processes are grounded. Interdisciplinary restoration efforts have enormous potential; however, restoration has suffered from lack of evaluation and lack of synthetic studies of past efforts. We outline a new initiative – the National Riverine Restoration Science Synthesis (NRRSS) – that involves a large interdisciplinary team of scientists and engineers working in partnership with the river conservation organization, *American Rivers.* Participants are assembling a data set that spans multiple ecoregions and many types of restoration activities performed by diverse groups with various stakeholders. We are addressing: what kinds of restoration activities, at what scale, and by what means have taken place; how goals were set and success measured; the extent to which scientific criteria were used; the extent to which adaptive management was an explicit component; and the extent to which scientists formed partnerships with restoration practitioners to use restoration projects as opportunities for scientific experimentation. The goal of the project is to facilitate the linkage between the practice of ecological restoration and the science of restoration ecology, as well as establish standards for data gathering and analysis to assess restoration methods and success in a scientifically rigorous manner.

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INTRODUCTION

Our goal in this paper is to elaborate on two themes. First, we argue that successful restoration of running-water ecosystems is best accomplished by collaborative teams that include ecologists, geomorphologists, and engineers. We outline why we believe such collaborations are essential. Second, we posit that the science of riverine restoration has suffered from lack of evaluation and lack of synthetic studies of past efforts. We outline a new initiative – the National Riverine Restoration Science Synthesis (NRRSS) – that involves a large interdisciplinary team of scientists working in partnership with the river conservation organization, *American Rivers.* As part of the NRRSS effort, we will be providing examples of successful collaborative restoration efforts at regular intervals on the *American Rivers* website. We preface our two themes with a brief overview of the urgent need for restoration as well as the need for additional scientific input in the design, evaluation, and prioritization of restoration efforts.

Science and Riverine Restoration

Ecological restoration has enormous potential to enhance ecosystem goods and services and to protect biodiversity (Dobson et al. 1997). Ecological restoration also provides enormous opportunities for ecologists to conduct large-scale experiments and test basic ecological theory (Young et al. 2001). Indeed, the development of restoration ecology as a science is dependent upon tests of relevant ecological theory being linked to actual restoration projects. Likewise, to maximize the success of restoration projects, ecological restoration (the practice) should be informed and guided by restoration ecology (the science) (van Diggelen et al. 2001). Of the thousands of restoration activities that take place annually, only a small fraction benefit from the combined insights of practitioners and scientists.

Streams and rivers have arguably experienced some of the most dramatic forms of habitat simplification of any type of ecosystem (Allan and Flecker 1993, Stanford et al. 1996, Sala et al. 2000). Because rivers are so important economically and ecologically, restoration of these ecosystems is receiving a lot of attention and enormous financial support (Cairns 1995, Gore and Shields 1995, Karr and Chu 1999). Restoration activities are diverse, ranging from channel engineering, to hydrologic experimentation, renewal of riparian vegetation, bank stabilization, and habitat improvement (Gore and Shields 1995, Gore et al. 1995, Kondolf 1995, Riley 1998, Rosgen 1996, Smith et al. 1995, Stanford et al. 1996), and even dam removal (Hart and Poff 2002). All levels of government, as well as volunteer groups, businesses, and non-governmental organizations are involved in restoration efforts. Projects vary in scope from some of the largest imaginable (e.g., the Everglades), to small reaches of headwater streams.

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COLLABORATING TO RESTORE RUNNING-WATERS

Developing methods, designing plans and implementing riverine restoration projects have historically been the purview of engineers. We suggest that projects will benefit by iterative, intertwined efforts by researchers and practitioners from multiple disciplines. In the ideal situation, restoration teams will be working in conjunction with community groups, watershed managers, and other stakeholders. To be most successful, teams should be composed of geomorphologists, engineers, and ecologists. If members of each discipline work solo or in tandem assuming that integration can be done *post facto,* projects are less likely to succeed. Team members working side by side from the beginning can first identify the major obstacles and then brainstorm solutions – each of the disciplinary members bring different skills and knowledge to the table.

While the role of engineers in riverine restoration is certainly important, the input of geomorphologists and ecologists provides insights not typically provided by engineers. Stream structure and function from a flow, sediment, or biological perspective are inextricably linked to channel dynamics and sediment movement. Benda et al. (2002) recently emphasized that engineering has made major contributions to quantitative geomorphology by addressing problems related to sediment transport and landslides. Certainly these approaches and sediment transport theory provide platforms for restorationists to address issues related to channel dynamics as well as, the entrainment, movement, and deposition of sediments (ASCE 1998). However, the utility of sediment transport theory may decline with increasing scale or environmental context (Benda et al. 2002).

The study and understanding of environmental context is fundamental to the ecological and geomorphic sciences. Experienced geomorphologists have a firm understanding of how best to incorporate into restoration projects knowledge of local geology, channel response to change in sediment regimes (e.g., in sediment starved urban settings), and geomorphic legacies (Harding et al. 1998). Their understanding is largely derived from empirical work and the recognition that restoration methods that rely solely on modeling or equation-based approaches (e.g., using "hydraulic geometry" regression equations; Leopold et al., 1964) may fail if the local geomorphic dynamics are not taken into consideration.

Historically, ecologists have rarely been present at the restoration 'design table'. Like geomorphologists, their input is unique and essential to restoration projects. If we hope to return running-water ecosystems to 'healthier' states, we must evaluate the interplay between on-site ecological processes (e.g., productivity, biogeochemical transformations, habitat suitability, etc.) and the hydrologic and geomorphic context in which these processes are grounded. Biological diversity and ecological processes are inextricably linked to the flux of water and sediments (Allan 1995, Poff and Ward 1990). To predict changes in biota and ecological processes under different restoration scenarios, ecologists can critically evaluate the extent of disturbance in a broad spatial and temporal context that incorporates an understanding of landscape ecology, metapopulation dynamics, biotic dispersal, and biophysical interactions (Roth et al. 1996, Palmer et al. 1997, Poff et al. 1997). Ecologists have the ability to use empirically-based knowledge of riverine ecosystem dynamics in combination with ecological models to evaluate potential responses to changes in channel form and the associated changes in the flow and sediment regimes. Examples of successful efforts to link multiple types of models in some spatial context include analyses as comprehensive as projects to assess the ecological impacts of hydrologic management of the Everglades. A multimodeling approach used in the Everglades project has combined physical models for hydrology with ecological models to address problems operating at different scales of space, time, and data resolution scales and is an approach applicable to similar systems such as the Pantanal in Brazil, Bolivia and Paraguay (DeAngelis et al. 1998, Swarts 2000).

NATIONAL RIVERINE RESTORATION SCIENCE SYNTHESIS

While some restoration efforts are being catalogued, few are evaluated for ecological success. Further, while there has been some predictive work – what might happen if certain restoration activities are implemented — there has been little pre- and post-project monitoring and analysis to assess the outcomes of those activities. When these projects are monitored and analyzed, it is typically at only a local or single-site scale, and is limited to a visual survey of the integrity or stability of in-stream structures; the ecological functioning of the stream is rarely considered. Successful stream restoration requires identification of the relevant biological and physical processes and requires an understanding of the interacting nature of these processes (Hobbs and Harris 2001).

The post-restoration analyses that have been done are not always translated and disseminated effectively to practitioners and grassroots watershed groups who are trying to restore streams. In addition, there has been no synthesis of these evaluations to draw broader conclusions and develop practical and policy recommendations. For example, throughout the United States, local governments have sponsored river and riparian restoration projects or agreed to those projects as mitigation for damage done elsewhere on the river. Yet we do not know if these projects are providing the ecological services lost elsewhere.

Both the development of restoration ecology as a science and the success of restoration projects depend on linking the practice with the science, yet many thousands of stream restoration activities take place annually, only a fraction of which benefit from the combined insights of practitioners and scientists. For example, miles of stream and river banks have been stabilized and planted with trees, but little monitoring data were collected before and after the projects to evaluate their success. Decisions are being made about the types and locations of restoration projects with limited information on their effectiveness. Restoration projects are authorized to serve as mitigation for damages done to many streams and wetlands without knowing if these mitigation projects are truly effective.

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The National Riverine Restoration Science Synthesis is the project of a working group through the National Center for Ecological Analysis and Synthesis and American Rivers (Table 1). The NRRSS project is organized into seven regional nodes in which our efforts are concentrated – these nodes span the diverse geographic and climatic regions throughout the United States (Figure 1). Further, the type, motivation, and extent of restoration projects vary dramatically among the different nodes (Table 2). Our goal is to analyze the extent, nature, scientific basis, and success of river restoration projects, and to present this information in a way that is useful to scientists, restoration practitioners, and those making policy decisions on what kinds of projects ought to receive priority for funding and implementation. This approach will place each node's river restoration projects into both a regional and national perspective.

Specifically, we are synthesizing the state and regional data to (1) evaluate the status of the practice of river restoration nationally and identify successful demonstration of different types of stream restoration, highlighting the reasons for their success; (2) produce a scientific document that examines the links between ecological theory and river restoration, such as the roles of refugia, connectivity, and natural processes, as well as the unanswered questions meriting further research; (3) develop a series of specific recommendations to improve how river restoration is carried out and its success evaluated; and (4) disseminate this information broadly on an on-going basis.

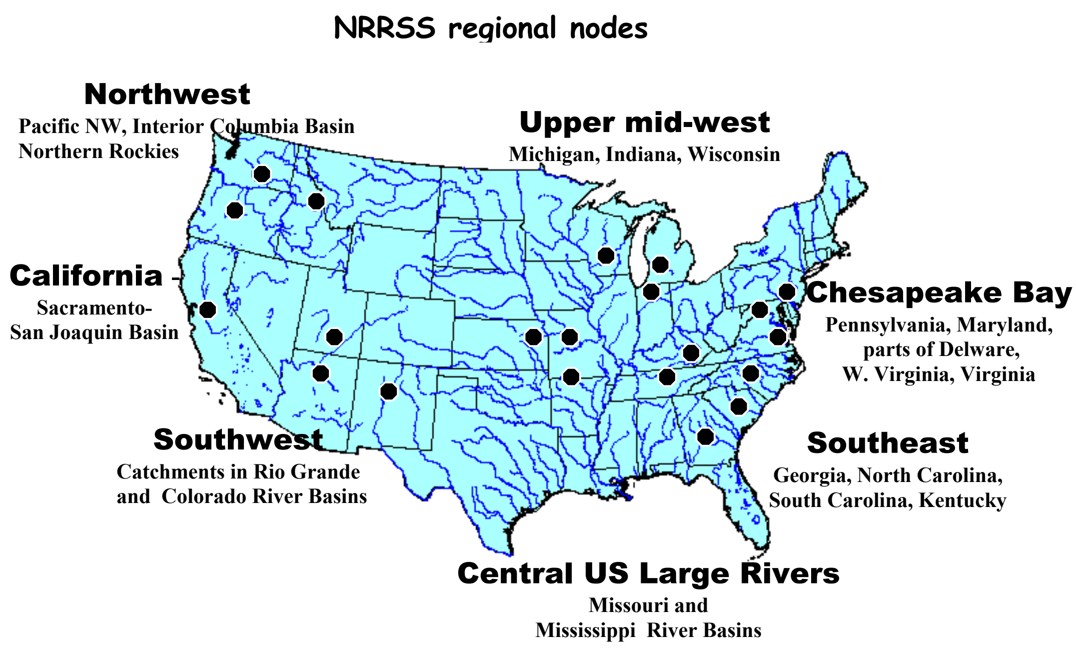

Figure 1. Location of regional nodes for data collection and synthesis as part of the National Riverine Restoration Science Synthesis project.

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Table 1. Regional node scientific team members and *American Rivers* team members for the National Riverine Restoration Science Synthesis project. Additional project information available at www. AmericanRivers.org.

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Midwest Node	
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David Galat	Department of Fisheries and Wildlife, University of Missouri-Columbia, Columbia, MO 65211
Northwest Node	
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Table 2. Dominant types of restoration efforts for various regional nodes (based on preliminary data for the NRRSS project.)

Northwest: projects related to habitat rehabilitation for better salmon fisheries

Upper Mid West: streambank stabilization and salmonid habitat improvements

Chesapeake Bay: streambank grading, matting/live stakes and riparian planting; stormwater management; bank stabilization

Southeast: bank stabilization; channel reconfiguration; riparian planting

Central US Large Rivers: channel widening, channel-floodplain reconnection, sandbar/island reconstruction, flow management

Southwest: native species conservation; exotic species management; endangered species recovery; flow regime management

California: channel reconstruction and levee alteration; gravel augmentation; fish Screens & habitat improvements; riparian planting & fencing; bank stabilization in urban channels

We are in the process of identifying a representative sample of successful restoration projects within each node. We began by accessing the many national databases that are available (Table3) and are currently working with many partners to incorporate much more extensive and detailed information from regional and local sources. We are actively seeking input from stream restoration practitioners. Individuals with knowledge of restoration projects are encouraged to contact one of authors of this paper or a participant in the project (Table 1). We intend to produce recommendations for improving the practice of stream restoration and to disseminate this information to practitioners and interested citizens throughout the country. To date we have already amassed over 10,000 projects and welcome any additional input and/or partnerships.

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Table 3: List of national databases that include information on river restoration projects thus far accessed by NRRSS participants.
USDA-NRCS-EQIP
USDA-NRCS-WHIP
USDA-NRCS-CRP
USDA-Forest Service Fisheries
USDA-Hazardous Materials Management
USDA-USFS-Stewardship Incentive Program
USDA-NRCS-Conservation Technical Assistance
USDA-FSA-Emergency Conservation Program
USDA-USFS-Taking Wing
USDA-NRCS-Watershed Protection and Flood Prevention
National Fish and Wildlife Foundation
Partners for Fish and Wildlife
National Marine Fisheries Service
National Marine Fisheries Service
US Fish & Wildlife Service, Division of Federal Aid
US Fish & Wildlife, Cooperative Endangered Species Conservation Fund
NOAA Coastal Zone Management Administrative Awards
USACE Aquatic Plant Control
USACE Section 1135
USACE Civil Works Environmental Program
BLM Riparian Wetlands Initiative
DOT TEA21
EPA Sustainable Development Challenge Grants
EPA- 5 star program
EPA -CWA sec. 319
National Park Service Project Management Information System

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