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Ecosystem Restoration to Restore Water Quality; An Unrealized Opportunity for Practitioners and Researchers

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Ecosystem Restoration to Restore Water Quality; An Unrealized Opportunity for Practitioners and Researchers

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Foreword

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threatens human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Restoration of ecosystems is increasingly proposed as a strategy for improving water quality. Although this approach makes intuitive sense, practitioners have received little guidance from researchers on the effectiveness of and concerns associated with particular techniques. Now, as governments debate the merits of implementing restoration programs, there is a need to justify and design such actions with data. This review includes a representative set of articles concerning riparian management and restoration: categorizing them to identify patterns that can lead to miscommunication. The riparian management literature is unusually dispersed both in the sense that as a subject matter it is covered in many journals and projects are geographically dispersed. Thus, people approach the concept of riparian restoration from an unusual variety of perspectives and with a wide array of experiences. While this condition has the high probability of promoting and fostering miscommunication, we hope that this review will improve the awareness of these issues and will enhance communication.

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Executive Summary

Restoration of ecosystems is increasingly proposed as a strategy for improving water quality. Although this approach makes intuitive sense, practitioners have received little guidance from researchers on the effectiveness of and concerns associated with particular techniques. This reflects a fundamental disconnect between researchers and practitioners, with research targeting narrowly focused, discipline specific topics (e.g., researchers interested in restoration of plant communities do not investigate water quality, water quality researchers do not investigate plant communities, and specialists from both disciplines seldom interact).

Restoration Ecology is unique in part because professionals were slow to recognize it as a stand-alone discipline. Restoration's pioneers were more interested in 'doing versus measuring.' Now, as governments debate the merits of implementing restoration programs, there is a need to justify and design such actions using data. The U.S. EPA in particular is interested in restoration's potential as a means to affect water quality. This raises several interesting issues, some of which are predominantly academic and others that have wide-ranging implications. The *ad hoc* development of restoration as a discipline makes it particularly susceptible to historic and regional influence. We sought to identify patterns in the restoration literature that effect communication and therefore restoration science, particularly with regard to the goal of using restoration as a tool to improve water quality.

This review includes a representative set of 294 articles concerning riparian management and restoration. In order for a paper, book, or other contribution to be selected as representative, it had to discuss data in the context of riparian ecosystems, and it also had to discuss at least one or more of three subject categories: 1) environmental management practice, 2) water quality, and/or 3) riparian restoration. Thus, our review is limited to riparian management research that discusses water quality and/or restoration.

Our review of the riparian restoration literature identified patterns that can lead to preconceptions and interfere with communication. The riparian management literature is unusually disparate both in the sense that as a subject matter it is covered in many journals and projects are geographically dispersed. Thus, people approach the concept of riparian restoration from an unusual variety of perspectives and with a wide array of experiences. This condition has the high probability of promoting and fostering miscommunication. Among the new perspectives being brought to riparian management is a need to use restoration to improve water quality. This is a narrow view of restoration. Attempting to focus restoration this narrowly will require ongoing communication and definition not only regarding 'restoration', but also for 'riparian' and 'water quality.'

Contents

Figures

Table

Acknowledgments

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Introduction

Restoration of ecosystems is increasingly proposed as a strategy for improving water quality. Although this approach makes intuitive sense, practitioners have received little guidance from researchers on the effectiveness of and concerns associated with particular techniques. This reflects a fundamental disconnect between researchers and practitioners, with research targeting narrowly focused, discipline specific topics (e.g., researchers interested in restoration of plant communities do not investigate water quality, and water quality researchers do not investigate plant communities; and specialists from both disciplines seldom interact).

Restoration ecology is unique. Whereas disciplines typically begin with debates among academics and/or professional practitioners, restoration began with individual actions by caring stewards (Aronson et al. 1995; Hobbs and Norton 1996; Ehrenfeld 2000). The professional community was slow to recognize restoration as a stand-alone discipline (e.g., Pickett and Parker 1994). Indeed, this has occurred only in the past decade. Restoration's pioneers were more interested in 'doing versus measuring.' In our estimation, they had empirical faith that their actions were beneficial and considered pursuing those actions to be more important than measuring effectiveness. (Note: this does not mean that effectiveness was not achieved, only that it was not measured). Of course, these conditions were unsatisfactory to professional ecologists and academicians who needed data. Now, as governments debate the merits of implementing restoration programs, the need to justify and design such actions using data is critical.

The U.S. EPA in particular is interested in restoration's potential as a means to affect water quality. This raises several interesting issues, some of which are predominantly academic, and others that have wide ranging implications. For instance, whereas restoration seeks whole system improvement, to what extent does improvement of a single ecosystem constituent constitute restoration? Have we conducted restoration when water quality alone has been improved? Is there a responsibility to measure other ecosystem responses in addition to water quality measures? Do we conduct restoration to improve ecosystems and expect water quality improvement as a collateral benefit, or do we conduct restoration to improve water quality and expect ecosystems to improve? To what extent does restoration targeted to improve water quality collaterally improve other ecosystem constituents? If we stop restoration at achieving water quality improvement, which other ecosystem constituents and services can we also expect to beneficially affect and which can we expect to remain unaffected?

In our view, the *ad hoc* development of restoration as a discipline makes it particularly susceptible to historic and regional influence. We sought to identify patterns in the restoration literature that affect communication and therefore restoration science, particularly with regard to the goal of using restoration as a tool to improve water quality. Efforts to synthesize these data in the past have either noted a lack of data (e.g., Manci 1989) or relied substantially on empirical observation and "best practices" (e.g., Federal Interagency Stream Restoration Working Group 1998). Particularly, we also sought to investigate the extent to which improved water quality has been targeted as an important outcome of whole system improvement through restoration.

The primary purpose of this literature review was to collect a representative set of riparian management and restoration articles, to identify associations between restoration concerns and water quality issues, and to improve the level of collaboration and interaction among practitioners and researchers. Secondarily, the survey sought to identify riparian ecosystem studies with a focus in three key categories: 1) studies on nonpoint source pollutants that affect water quality, 2) environmental management practices that yield these nonpoint source pollutants, and 3) restoration activities planned or conducted on these riparian ecosystems.

Restoration is …

Our initial step is to clarify what 'restoration' is and contrast its distinguishing characteristics with related management practices. This has been done several times in the past, but it bears additional discussion in the context of this paper, because knowing what restoration is helps to clarify why improvement of water quality can be an emergent benefit of whole ecosystem improvement.

Restoration is a complex discipline (Ehrenfeld 2000) incorporating ecology, biology, socioeconomics, and political science (among others) (e.g., Bradbury et al. 1995; Nehlsen 1997; Allen et al. 1997). These disciplines bring different perspectives and importantly, different linguistic traditions and internal definitions (Lewis 1990; Kentula 2000). Thus, the readily understood apparent meaning of 'restoration' ironically serves to contribute to miscommunication (*Sensu* National Research Council 1992; Kentula 2000).

Restoration's roots are deeply tied to opportunistic and site specific applications (Aronson et al. 1995; Hobbs and Norton 1996) conducted by true visionaries (note: Ehrenfeld [2000] discusses other roots of restoration). It is only recently that restoration achieved respectability among 'serious scientists' (e.g., Pickett and Parker 1994). Therefore, it is not surprising that restoration's paradigm continues to develop.

The ultimate goal of restoration is ecological and thus the potential ecological benefits are of utmost concern (Kentula 1997; Pastorok et al. 1997; Pelley 2000). However, many restorations focus on single ecosystem responses and do not account for the dynamic properties of ecosystems (Pelley 2000). It is a sign of growing maturity that planned restorations now routinely consider multi-disciplinary issues (Goodwin et al. 1997; Pelley 2000). However, much work remains to be done to promote actual incorporation of these issues into restoration design and implementation.

Restoration is still a very young science (Goodwin et al. 1997). Use of the term 'Restoration' has been preceded and accompanied by use of similar terms with similar meanings including 'Reclamation', 'Rehabilitation', 'Recovery', 'Replacement', and 'Remediation' (e.g., Meffe and Carroll 1994; Jackson et al. 1995; Hobbs and Norton 1996; Federal Interagency Stream Restoration Working Group 1998; Kentula 2000; Ormerod 2003). Clearly, these terms share close linguistic relationships, and they are frequently used interchangeably. However, especially in the natural resource specialties, close attention to detailed (usually implied) meanings underlying these terms is important (Ormerod 2003), and such differences are widely recognized, if not necessarily agreed upon (Meek 1995; Bradshaw 1996). While it may be of academic interest to sort through the etymology of these terms (particularly as they are applied in the natural resource management specialties), searching for agreement on terminology remains, as it was for Hobbs and Norton (1996), a task that is destined for frustration. However, continued efforts to highlight the characteristics of 'restoration' that distinguish it from similar practices are part of the discipline's continued development and is necessary when communicating with non-specialists.

Reclamation is a term with a longstanding history in relation to lands affected by mining (most specifically strip mining). 'Reclamation' is closely akin to 'restoration.' For example, the Office of Surface Mining has the responsibility to:

> "Protect(ing) the environment during coal mining and making sure the land is reclaimed afterward" (http:// www.osmre.gov/; March 2003).

In this context, reclamation is a widely used term and can refer to many types of desired endpoints (e.g., Arbogast et al. 2000). The essential difference between 'reclamation' and 'restoration' has to do with the extent and cause of the initial damage. 'Reclamation' has come to refer specifically to efforts to improve landscapes affected by mining. 'Reclamation' is most appropriate in instances where substantial initial damage has occurred, particularly with relation to mining. In these instances, there may not be much of the initial ecosystem remaining to restore, but it is reasonable to reclaim some of the lost functions of the initial site by constructing a new landscape with both natural and anthropogenic values. 'Reclamation's' historic meaning is being supplanted within the 'reclamation' community by more holistic thinking. In some cases, 'restoration' may actually be a goal of 'reclamation' (Arbogast et al. 2000).

Rehabilitation is a term that is infrequently used. Meffe and Carroll (1994) illustrate rehabilitation as being equivalent to restoration in the early stages, but stopping short of restoration's ultimate goals. Arbogast et al. (2000) limit application to cases where the intended end use of the landscape is for public amenities. Rehabilitation also has connotations of returning to usefulness, although not necessarily a return to the original state or extent of usefulness. Rather, it focuses upon specific types of outcomes and seeks to improve (or rehabilitate) those without particular regard for collateral characteristics.

Recovery is a term most frequently applied to succession; ecosystems 'recover' from disturbance by following successional pathways. 'Recovery' is a natural ecological process that can be used in 'restoration.' However, whereas all sites will 'recover' if left undisturbed, not all sites will be 'restored' in this way. This is particularly true today where invasion by alien/exotic species is an important issue for restorationists. Whereas 'recovered' sites could include invasive flora and fauna, 'restored' sites would seek to minimize or eliminate their influence.

Replacement is a term that is not frequently used. In practice, 'replacement' is what often occurs with 'reclamation' of strip-mined sites; one ecosystem is removed and another is put in its place. Landfill caps could be considered to be 'replacements.' Components of ecosystems may be 'replaced.' For instance, the historic fisheries of the Great Lakes have been 'replaced' by new assemblages of fish (Ashworth 1987). Current controversies such as 'valley fill' are considered by some to amount to ecosystem 'replacement' and mirror debates from decades gone by concerning hydroelectric projects. The tallgrass prairie ecosystem of the midwestern United States has been 'replaced' by an agricultural ecosystem that emphasizes specific types of productivity.

Remediation has the clearest distinguishing characteristics compared to restoration. It is focused upon improving single environmental media (i.e., clean water, clean soil, clean air), especially due to effects from pollution. Remediation is the:

> "… process of removing, reducing, or neutralizing industrial soil and sediment contaminants that threaten human health and/or ecosystem productivity and integrity" (http://www.rr.ualberta.ca/Research/Land_Recl_Remed_Restor/index.asp; March 2003).

Restoration has the intent of viewing ecosystems, sites, and landscapes in their ecological and cultural contexts. Restoration carries the clear connotation of:

> "… manipulating an ecosystem (soil, vegetation, and wildlife) to achieve compositional, structural and functional patterns similar to the predisturbed condition" (http://www.rr.ualberta.ca/Research/Land_Recl_Remed_Restor/index.asp; March 2003).

To the media (soil, vegetation, and wildlife) listed above, it is easy to see also that provision of water, air, spatial, and cultural resources sufficient to promote restoration should be as important as "… soil, vegetation and wildlife …" resources. Also, it would be incorrect to assume too much intended meaning for the word "predisturbed". All natural systems are subject to disturbance (Pickett and White 1985; Cairns, Jr. 1991; Pickett and Parker 1994; Hobbs and Norton 1996). The distinguishing difference is between disturbances that ecosystems are adapted to (e.g., fire, flood, insect irruption) and disturbances that ecosystems cannot recover from in timeframes that humans are familiar with (i.e., habitat loss, habitat fragmentation, paving, dam building, urban sprawl, and industrialized agriculture).

The true implications of 'Restoration' can be further appreciated in the Society for Ecological Restoration's mission statement:

> "To promote ecological restoration as a means of sustaining the diversity of life on Earth and reestablishing an ecologically healthy relationship between nature and culture" (http://www.ser.org/ser.php?pg=mission; March 2003).

They define 'Ecological Restoration' as:

> "… the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (http://www.ser.org/reading.php?pg=primer2; March 2003).

Clearly, this definition has much in common with 'reclamation', rehabilitation', 'recovery', 'replacement', and 'remediation'. The distinguishing difference is in the endpoint or ultimate goal: 'Restoration' seeks to establish a condition that is self-regenerating, self-adapting, and self-maintaining (i.e., a predisturbed condition that supports and allows ecologically healthy relationships between nature and culture). 'Restoration' seeks whole ecosystem improvement (National Research Council 1992; Naveh 1994; Hobbs and Norton 1996; Kentula 2000; Zedler 2000) to a condition that is intended to model/reproduce/duplicate – '*restore*' – the ecosystem's original natural condition (e.g., Bradshaw 1996).

Methods

This survey utilized data from the primary literature (i.e., current and past research journals), as well as books, conference proceedings, websites, and governmental publications. The survey contains data mainly collected from North America; however, a minor number of international studies have been included. The literature survey focused primarily on the period from 1970 through 2002. The survey extent was intended to be sufficient to define patterns and to support our conclusions.

The literature survey was completed using a number of search tools. Key words included *riparian ecosystem*, *environmental management practices*, *water quality*, *nonpoint source pollutants*, and *riparian restoration*. For the purposes of this study we define these as follows:

Riparian Ecosystem – ecosystems in which soils and vegetative communities are influenced by adjacent streams or rivers, and which process large fluxes of energy, nutrients, biological, and physical materials.

Related Search Criteria; palustrine wetlands, riverine wetlands, gallery forests, floodplain forested wetlands, riverine fringe wetlands;

Environmental Management Practices – anthropogenic activities that affect natural processes and systems.

Related Search Criteria; agricultural, farming, fertilizer, pesticide application, grazing, sedimentation, forestry, temperature, urbanization, bacteriological, mining;

Water Quality – limited for this survey to non-point source pollutants, temperature, and pesticides.

Related Search Criteria; nitrogen species, phosphorus, temperature, sedimentation, pesticides, bacteriological;

Riparian Restoration – activities that return riparian ecosystems to historical natural structure and functions.

Related Search Criteria; water quality enhancement, riparian/wetland function, habitat enhancement, recreation potential and enhancement, modeling, planning/research/policy.

Databases that were searched included:

AGRICOLA; a bibliographic database consisting of literature citations for journal articles, monographs, proceedings, theses, patents, translations, audiovisual materials, computer software, and technical reports pertaining to all aspects of agriculture. This extensive database provides selective worldwide coverage of primary information sources in agriculture and related fields. The literature cited is primarily in English, but over one-third of the database comprises citations in Western European, Slavic, Asian, and African languages. The National Agricultural library indexes 2,233 journals for inclusion in Agricola. (http://alt1.csa.com/csa/factsheets/agricola.shtml; January 2003).

BIOLOGICAL SCIENCES; an interdisciplinary database offering abstracts and citations to a wide range of research in biomedicine, biotechnology, zoology and ecology, and some aspects of agriculture and veterinary science. Supporting over two dozen areas of expertise, this database provides access to literature from over 5,765 serials, as well as conference proceedings, technical reports, monographs and selected books and patents. (http://alt1.csa.com/csa/factsheets/biolset.shtml; January 2003).

ENVIRONMENTAL SCIENCES AND POLLUTION MANAGEMENT; a multidisciplinary database, providing unparalleled and comprehensive coverage of the environmental sciences. Abstracts and citations are drawn from over 5,980 serials including scientific journals, conference proceedings, reports, monographs, books, and government publications. (http://alt1.csa.com/csa/factsheets/envclust.shtml; January 2003).

GEOREF; a database, established by the American Geological Institute (AGI) in 1966, providing access to the geoscience literature of the world. GeoRef is the most comprehensive AGI database in the geosciences and continues to grow by more than 60,000 references a year. The database contains over 2.2 million references to geoscience journal articles, books, maps, conference papers, reports and theses. GeoRef covers the geology of North America from 1785 to the present and the geology of the rest of the world from 1933 to the present. The database includes references to all publications of the U.S. Geological Survey. Masters' theses and doctoral dissertations from United States and Canadian universities are also covered. GeoRef editor/indexers regularly scan more than 3,500 journals in 40 languages as well as new books, maps, and reports. They record the bibliographic data for each document and assign index terms to describe it. Each month between 4,000 and 7,000 new references are added to the database. (http://www.agiweb.org/georef/about/index.html; January 2003).

NTIS; a database produced by the National Technical Information Service, is the preeminent resource for accessing the latest U.S. government-sponsored research and worldwide scientific, technical, engineering, and business-related information. It contains over 2.1 million titles from 1964 until the present. NTIS is the central source for the sale of unclassified and publicly available information from research reports, journal articles, data files, computer programs, and audio-visual products from Federal sources. (http://alt1.csa.com/csa/factsheets/ntis.shtml; January 2003).

WEB RESOURCES; a natural sciences database featuring a collection of over 145,000 high-quality web sites, related to environmental, aquatic, and biomedical topics, that are hand-picked and indexed by Cambridge Scientific Abstracts editors. This includes only sites containing specific, technical information of interest to a college-level audience, from respected, nonbiased sources such as educational institutions, government agencies, and scientific organizations.
(http://alt1.csa.com/csa/factsheets/ird-BE.shtml; January 2003).

CONFERENCE PAPERS; a database providing citations to papers and poster sessions presented at major scientific meetings around the world. Subject emphasis since 1995 has been in the life sciences, environmental sciences, and the aquatic sciences, while older material also covers physics, engineering, and materials science. Information is derived from final programs, abstracts, booklets, and published proceedings, as well as from questionnaire responses. Records include complete ordering information to obtain preprints, abstracts, proceedings, and other publications derived from the conference, together with title and author information needed to track the specific papers. The database contains over 1.2 million records from 1982 until the present. (http://alt1.csa.com/csa/factsheets/cpilong.shtml; January 2003).

In order for a paper, book, or other contribution to be selected for inclusion in the literature review as representative, it had to discuss data in the context of riparian ecosystems, and it also had to discuss at least one or more of three subject categories: 1) environmental management practice, 2) water quality, and/or 3) riparian restoration. In this way we sought to limit our representative literature to riparian management research that discussed water quality and/or restoration.

Results

We collected 294 papers, including contributions from 46 journals. The most frequented journal for this survey was the *Journal of the American Water Resources Association* (JAWRA). The survey also found relatively frequent contributions in *Ecological Applications*, *Environmental Management*, *Journal of Environmental Quality*, *Journal of Soil and Water Conservation*, and *Wetlands*.

Table 1. Primary Literature Sources

Journal Titles (Alphabetical)	# of papers
Aspects of Applied Biology	1
Agricultural Science in Finland	1
Biogeochemistry	3
Biological Fertility of Soils	1
Bioscience	1
Conservation Biology	1
Ecological Applications	9
Ecological Engineering	1
Ecological Modeling	1
Ecology	1
Environmental Management	5
Fisheries	1
Forest Ecology and Management	4

Forest Science	2
Freshwater Biology	1
Freshwater Wetlands and Wildlife	1
Geomorphology	1
Journal of Applied Ecology	1
Journal of Arizona Academy of Sciences	1
Journal of Environmental Management	1
Journal of Environmental Quality	10
Journal of Forestry	2
Journal of Hydrology	2
Journal of Range Management	1
Journal of Soil and Range Conservation	1
Journal of Soil and Water Conservation	7
Journal of the American Water Resources Association	35
Manure Management	1
Michigan Academician	1
Native Plants Journal	1
Rangelands	3
Restoration and Management Notes	2
Restoration Ecology	4
Science	1
Soil Biology and Biochemistry	1
Soil Science Society of America Journal	2
Southern Journal of Applied Forestry	1
Trans. of the American Society of Agricultural Engineers	1
Trans. of the N. American Wildlife and Natural Resources Conference	1
Trans. of the American Fisheries Society	1
Water Environment Research	1
Water Research	2
Water Resources Bulletin	3
Water Resources Research	3
Water Science and Technology	2
Watershed Research Perspectives	2
Wetlands	5

Papers from peer-reviewed journals accounted for 46% of all sources. Additional sources included chapters taken from textbooks, symposia proceedings, governmental reports, and contributions from websites. While a few journals regularly contain relevant contributions, there are a large number of journals that publish irregularly in this subject area (Figure 1).

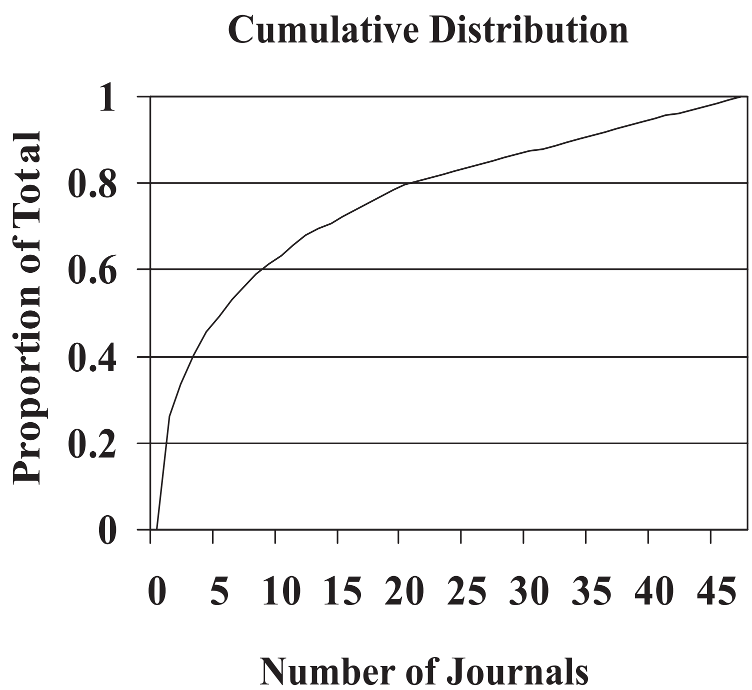

Figure 1. There are a few journals that regularly publish articles relevant to riparian management. However, many journals cover the topic irregularly, suggesting that relevant information for riparian restoration is dispersed.

In the United States, riparian restoration publications are disproportionately represented in the Northwest and Southeast (53.4% of citations; Figure 2a). The Northeast is poorly represented (9.5% of citations; Figure 2a). In both instances, this pattern is long established. Manci (1989) documented a similar pattern before "restoration" became an item of substantial interest (60.9% and 6.5% of citations respectively; Figure 2b).

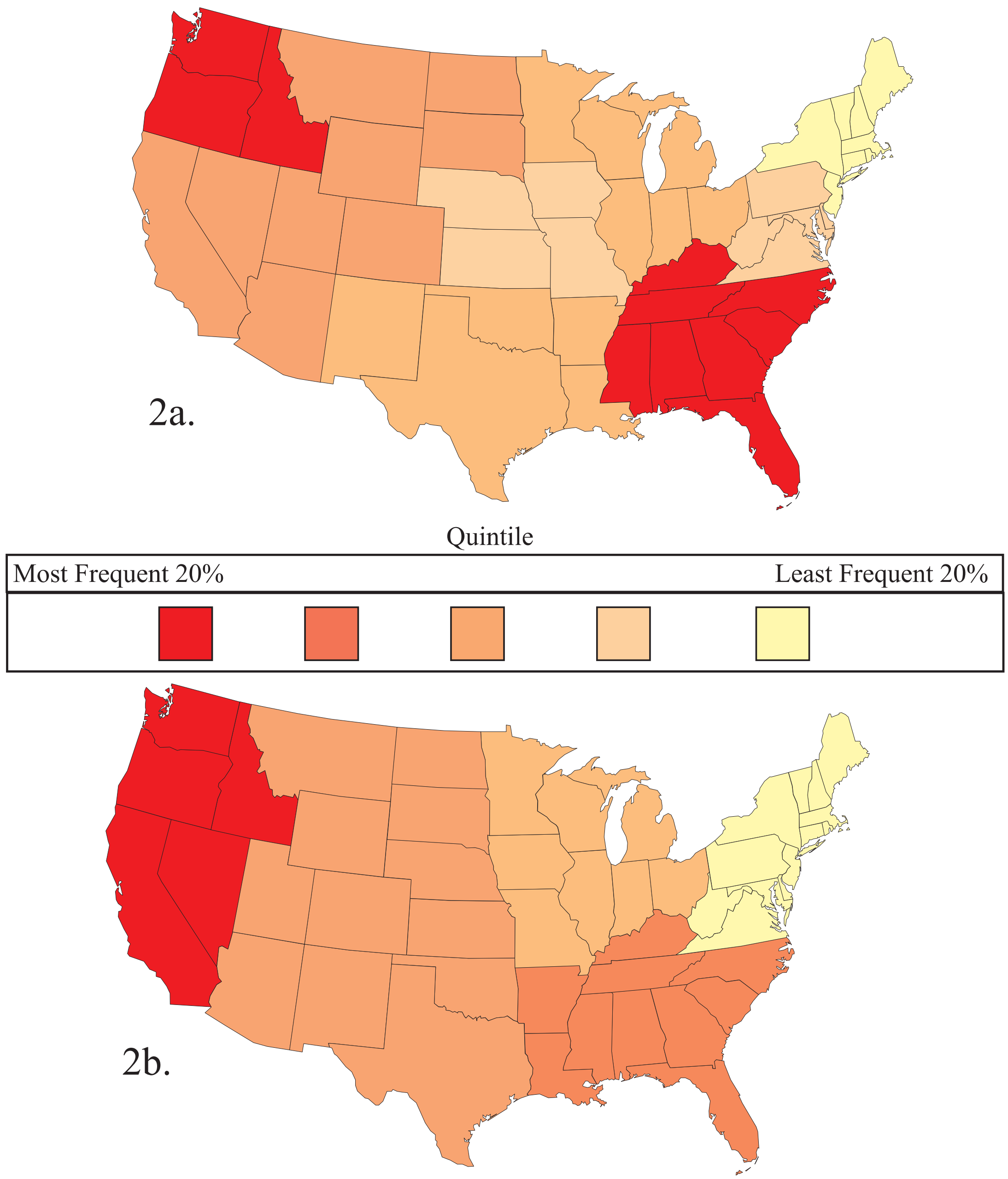

Figure 2. Geographic distribution of riparian restoration research according to EPA Region for this research (Fig. 2a) and by USFWS Region according to Manci (1989)(Fig. 2b).

Stressors covered by our selected sources were (necessarily) limited by our search criteria (see Methods). Within our criteria, papers addressing nitrogen, phosphorus, and sediment loading occurred with high frequency, whereas contributions concerning temperature, pesticides, or bacteria were infrequent (Figure 3), accounting for <20% of selected sources.

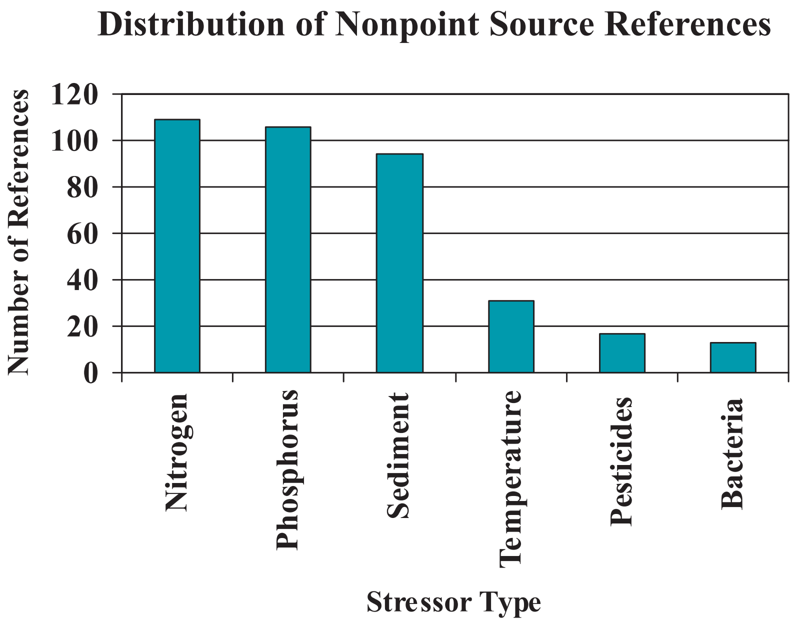

Figure 3. Most riparian restoration research addresses non-point nutrient and sediment concerns.

Contributions concerning use of restoration in conjunction with agricultural management practices accounted for more than twice as many papers as the next most common environmental management practice. Of the remaining three practices, forestry was the second most commonly found, urbanization was third, and mining represented the least number of papers (Figure 4).

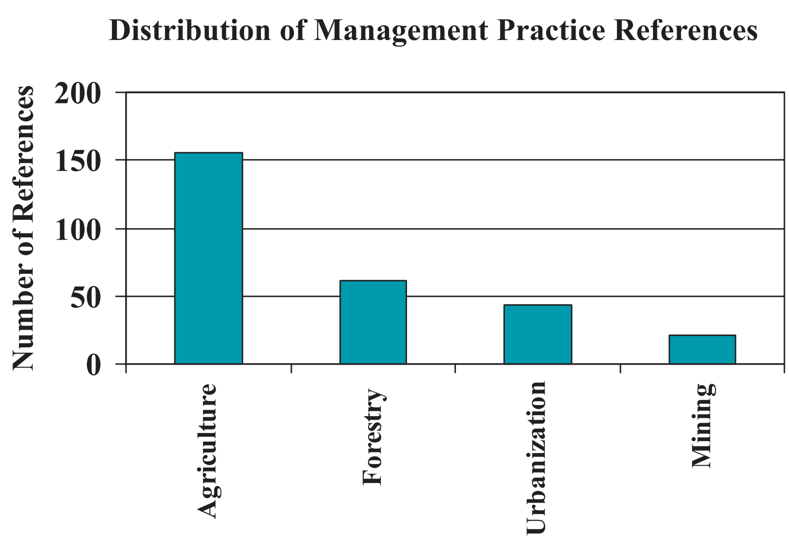

Figure 4. Riparian restoration has been most frequently discussed with regards to addressing agricultural affects.

Not surprisingly, within these management practices, studies tended to focus on different stressors – with predominant attention being paid to a few (Figure 5). Agricultural management practice papers dealt primarily with nitrate, phosphorus, and sediment issues, with substantially fewer papers covering temperature, biological pollutants, and pesticides. Forestry management practice papers focused on sediment loading issues. Urbanization papers were diverse, splitting their focus between nitrogen species, phosphorus, and sediment. Mining management practice papers dealt primarily with sediment issues, with less focus on nitrogen, phosphorus, and temperature.

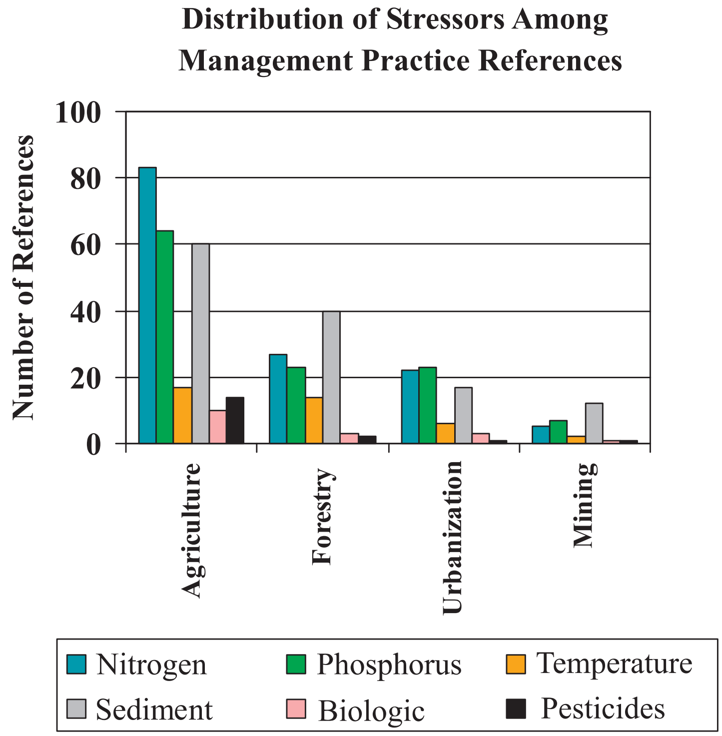

Figure 5. Stressors of interest vary with predominant landuse, although nutrients and sediment are well represented.

The total number of studies considering some form of riparian restoration (including reclamation, rehabilitation, recovery, replacement, remediation) was 41% (121 studies out of the 294). These were broken down into three basic categories, including: 1) planning/policy/overview, 2) restoration of site physical characteristics, and 3) restoration of vegetation. Most restoration papers relate primarily to project planning and contain no information concerning restoration performance (even broadly defined) (Figure 6).

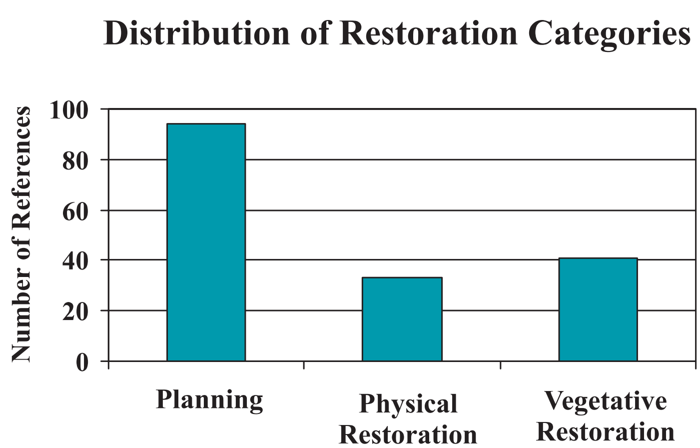

Figure 6. While restoration is being considered more frequently, the extent of the consideration is often in planning contexts.

Sediment was the most frequently considered stressor among all riparian restoration papers (~37% of total) (Figure 7). This stands somewhat in contrast with data presented earlier, leading to an expectation that nutrients would be focused upon most heavily (Figures 3 & 5).

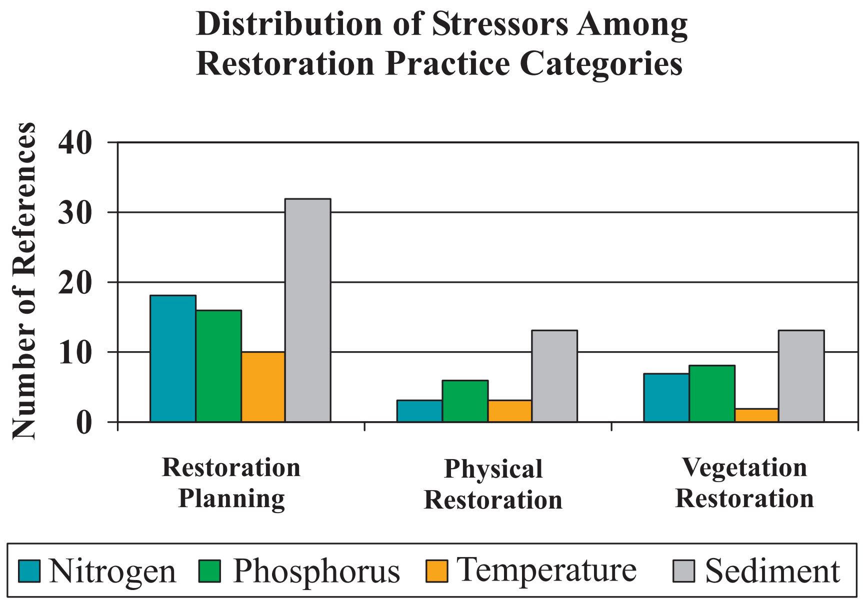

Figure 7. Water quality issues addressed in the restoration literature are essentially limited to traditional non-point concerns.

There are 49 papers that incorporate data on non-point pollutant sources affecting water quality, discuss environmental management practices that contributed to the water quality effects, and then describe some aspect of riparian restoration (even broadly defined). However, of these, only 22 present actual data on restoration efforts. The remaining 27 papers discuss restoration in terms of planning, research, policy, or as a general overview of the process and do not report data (Figure 8).

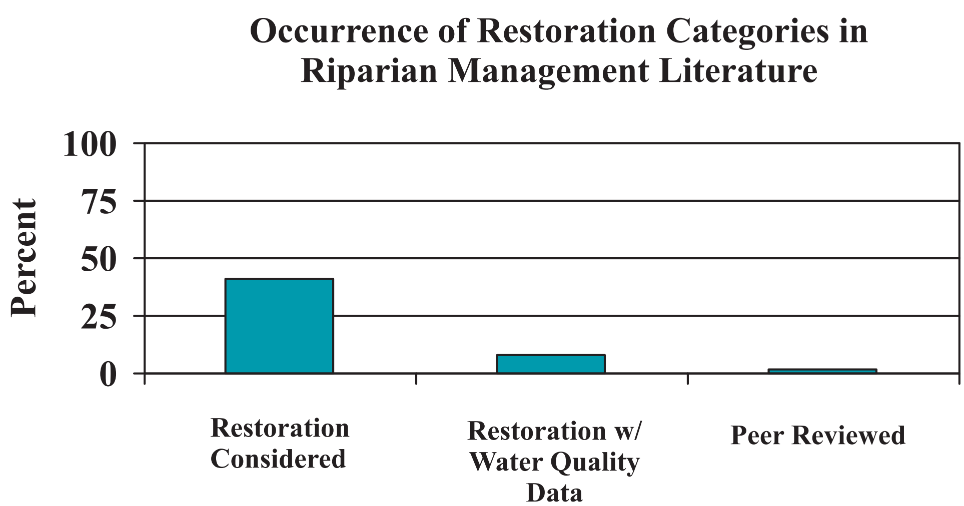

Figure 8. While restoration is frequently discussed with regards to riparian management, it is infrequently mentioned as a tool to address water quality – and data are particularly scarce.

Of the 22 papers that provided data on actual restoration efforts, only seven of the papers were presented in the primary literature (i.e., scientific research journals). These seven papers were carefully reviewed to determine the nature of the project efforts. None of the seven papers can be clearly described as being restoration oriented. Excerpts from the abstracts of these papers, which clearly meet our goal of presenting water quality data along with descriptions of associated 'restoration' practices, are presented below.

1. Heede, B. 1979. Deteriorated watersheds can be restored: a case study. Environmental Management, Vol. 3, No. 3.

   Management Mode: Rehabilitation

   A project in west-central Colorado demonstrated that a watershed dissected by a dense gully network can be stabilized and rehabilitated. Check dam systems, aided by improved vegetative cover through reduced cattle grazing and plantings, stabilized not only the structurally treated gullies, but also gullies within the network that were not structurally treated. Within 11 years after treatment, check dam systems and improved vegetation reduced sediment loads in the flows by more than 90 percent. From this work, they were able to conclude that only part of a gully network requires structural treatment. The mainstem gully, and those tributaries controlling the local base levels of others, are the critical segments that should be structurally treated.

2. Young, R.A., T. Huntrods, and W. Anderson. 1980. Effectiveness of vegetated buffer strips in controlling pollution from feedlot runoff. Journal of Environmental Quality, Vol. 9, No. 3.

   Management Mode: Remediation

   This study in west-central Minnesota measured effectiveness of sorghum, grass, and oat buffer zones for nitrogen, phosphorus, and coliform removal from feedlot runoff. Some water infiltrated and its quality was not measured. Total nitrogen and total phosphorus were reduced by 84% and 83%, respectively. Total solids in runoff were reduced by 79% in the cropped buffer strips. During the two-year study, the numbers of coliform bacteria were reduced after passing through vegetated buffer strips. The results indicated that nonstructural discharge control practices could reduce pollution in runoff waters from agricultural feedlots.

3. Rice, R. M. 1999. Erosion on logging roads in Redwood Creek, Northwestern California. Journal of the American Water Resources Association, Vol. 35, No. 5.

   Management Mode: Reclamation

   Road-related erosion was estimated by measuring 100 randomly located plots on a 180 km road network in the middle reach of Redwood Creek in Northwestern California. A sizable portion of the reduction in sediment load reported in earlier studies was attributed to changes in forest practice rules. The changes in forest practices included better placement and sizing of culverts, and less reliance of culverts to handle runoff from logging roads.

4. Entry, J.A., P.K. Donelly, and W.H. Emmingham. 1994. Microbial mineralization of atrazine and 2, 4-dichlorophenoxyacetic acid in riparian pasture and forest soils. Biology and Fertility of Soils, Vol. 18.

   Management Mode: Remediation

   This study was conducted in western Oregon and measured rates of degradation of the herbicides atrazine and 2,4-D in soils and litter of forested and grassed (pasture) riparian zones. It also measured microbial biomass in the study site soils. The study found that forested riparian buffer strips have higher levels of bacterial and fungal biomass than riparian pasture ecosystems.

5. Uusi-Kamppa, J., and T. Ylaranta. 1992. Reduction of sediment, phosphorus and nitrogen transport on vegetated buffer strips. Agricultural Science in Finland, Vol. 1.

   Management Mode: Remediation

   The largest source of phosphorus and nitrogen in surface waters is cultivated soil. The effects of 10-meter wide grass buffers for removing sediments and nutrients from farm croplands were studied for a 1-year period in Finland. The grass buffer strips decreased loads of total solids, phosphorus, and nitrogen by an average of 23, 6, and 47%, respectively. The grass buffer strips were effective in autumn and spring.

6. Robinson, C.A., M. Ghaffarzadeh, and R. M. Cruse. 1996. Vegetative filter strips effects on sediment concentration in cropland runoff. Journal of Soil and Water Conservation, Vol. 50, No. 3.

   Management Mode: Reclamation

   Erosion control techniques must be designed for high- and very high-intensity storms. This study, conducted in Iowa, indicates that a minimum vegetated filter strip width of 9.1 m could limit sediment *loading of streams from cropland runoff by 85%. More work is needed to reduce sediment loads to desirable levels.*

7. Reungsang, A., T.B. Moorman, and R.S. Kanwar. 2001. Transport and fate of atrazine in Midwestern riparian buffer strips. Journal of the American Water Resources Association, Vol. 37, No. 6.

   Management Mode: Remediation

   The fate of pesticides entering Riparian Buffer Strips (RBS) has not been well documented. This study from Iowa compared the transport and fate of atrazine in soil of three-, five-, and nine-year old switchgrass (Panicum virgatum L.) RBS to that in adjacent soils cropped to a corn-soybean rotation or a grass-alfalfa pasture. Despite similar texture and organic carbon content, atrazine sorption was significantly higher in the RBS soil than in the adjacent cropped soil.

Discussion

Our review of the riparian restoration literature identified patterns that can lead to preconceptions and interfere with communication. We believe that communication will improve when potential biases and preconceptions are known and generally recognized. Among the strongest preconceptions we have encountered is the variable understanding of 'restoration.' While we have drawn substantial attention to the fact that 'restoration' is a new discipline and that there has been significant debate concerning the definition of 'restoration', a similar condition exists for 'riparian' research and management (Hawkins 1994). Understanding of what constitutes a 'riparian' ecosystem is also quite variable, and the increasing interest in 'restoration' over the past two decades is accompanied by an identical increase in 'riparian' subject matter over the same time period (Hawkins 1994).

The riparian restoration literature is well-dispersed both as a specialty (Table 1; Figure 1) and geographically (Figure 2). This represents a challenge for researchers, administrators, and practitioners. With so many potential sources, the chance of missing or overlooking relevant information is great. The probability that different individuals are approaching related issues from very different starting places is great. This stands in somewhat strong contrast to many other specialties where early academic efforts tend to focus subjects to where they are presented in just a few outlets that are well recognized. In riparian management and restoration, no such process has occurred. Thus, information is dispersed. Searches are complicated, time-consuming, and subject to unusually high rates of human error. This situation can be (in part) directly tied to substantive process inefficiencies including duplication of effort. It occurs to us that this is especially notable for restoration where process is critically important.

Our review of representative riparian restoration literature identified clear geographic patterns. In the continental United States, most literature pertained to either the Northwest or Southeast (Figure 2) with <10% of citations occurring in the Northeast. Ecological issues of greatest concern in the West and Southeast are disproportionately represented and restoration practices in those regions would be expected to be the most highly developed. Alternatively, restoration remains a relatively fresh concept in the Northeast. The potential that these geographic patterns may influence people's thinking and concepts seems self-evident to us. However, this has not been explored or considered in depth.

When restoration has been considered in concert with water quality, traditional non-point aquatic stressors (i.e., nitrogen, phosphorus, sediment) have been the focus (Figures 3 & 5). Thus, it is relatively easy to locate restoration research that deals with aspects of water quality. A more important question is how to deal with questions of water quality. Most projects relate primarily to planning, containing little or no information concerning restoration practices (even broadly defined) (Figure 6). Indeed, if one's interest primarily concerns effects of physical restoration practices on nutrients, the universe of available reference material becomes exceptionally small (Figure 7). Only 7.5 % of all available references contained water quality data. Even more telling, if one depends upon peer reviewed primary literature, one is left with only 2.4% of the available riparian management literature (Figure 8).

In summary, despite the robust nature of the overall body of literature concerning riparian ecosystem issues, there are relatively few that seek to correlate riparian water quality with environmental management practice, and subsequently with riparian restoration (note: with restoration loosely defined). While the total number of restoration papers gathered for this survey was a reasonable percentage of the whole (121 out of 294, or approximately 41%), the vast majority of the papers did not provide actual restoration data. Only seven papers (~ 2% of the total) could be identified from the primary literature that coupled discussions of historical environmental management practice, non-point source pollutants that resulted from that practice, and then detailed physical or vegetative restoration projects that would address these environmental problems. Further, none of these seven papers could justifiably be regarded as true restoration projects. Rather, the majority of the seven were remediation studies showing the benefit of using vegetated buffer strips for non-point source pollution control originating from agricultural fields, or reclamation studies showing change effected by installed structures such as culverts, berms, and check dams. While the concept of riparian restoration is widely discussed, its effectiveness for improving water quality is poorly documented, especially in the primary literature.

Conclusions

The riparian management literature is (in our view) unusually disparate. It is dispersed both in the sense that as a subject matter it is covered in many journals, and it is dispersed geographically. Thus, people approach the concept of riparian restoration from an unusual variety of perspectives and with a wide array of experiences. This condition has (in our view) the high probability of leading to miscommunication.

Among the perspectives being brought is a need to use restoration to improve water quality. This is a narrow view of restoration, and attempting to focus restoration this narrowly will require ongoing communication and definition not only regarding 'restoration', but also for 'riparian' and 'water quality.' A question we raised earlier seems most relevant here also; do we conduct restoration to improve ecosystems and expect water quality improvement as a collateral benefit, or do we conduct restoration to improve water quality and expect ecosystems to improve?

Specialists use 'restoration' when they seek whole ecosystem improvement. Historically, restoration has not been conducted to achieve water quality improvement. Restoration may be conducted on components (e.g., soil, vegetation) of watersheds, with the goal being to indirectly achieve water quality improvement.

Others have observed how the *ad hoc*, opportunistic nature of many restorations has led to a history of poorly documented follow through, with little to no record of effectiveness monitoring (Pickett and Parker 1994; Kondolf 1995; Aronson *et al.* 1995; Thom 2000). This literature review quantifies those observations.

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