Natural Resources and Environmental Issues

Volume 1 *Riparian Resources* Article 2

1-1-1994

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Abstract

Riparian areas represent less than 2 percent of all terrestrial ecosystems, but they are functionally one of the most important features within natural landscapes. They are characterized by high biotic production and diversity; they moderate flood intensity and store water; and they maintain high water quality by acting as nutrient and sediment sinks. These ecological functions make them valuable areas for a variety of human uses including agriculture, timber and livestock production, recreation, and housing. Human use, however, has resulted in severe degradation of the functional health of many riparian ecosystems. Recognition of the value of the systems and the magnitude of existing and continuing degradation has generated a concerted effort by natural resources managers and researchers to develop strategies to protect and restore riparian areas. Issues requiring particular attention are (1) development of a generally accepted definition of riparian ecosystems, (2) development of a functionally useful classification scheme of riparian areas, (3) quantification of the specific ways that human use causes ecological dysfunction, (4) collection of data from which we can objectively prioritize efforts to preserve extant systems, and (5) development of ecologically sound strategies for the restoration of degraded areas.

INTRODUCTION

Riparian ecosystems have attracted an increasing amount of attention from scientists and natural resources managers during the last two decades. This attention has been due to two developments: (1) recognition by scientists that these ecosystems play a profoundly important ecological role within natural landscapes and (2) recognition by natural resources managers that many riparian areas have been lost or severely degraded. The growing interest in riparian ecosystems is reflected in the number of scholarly articles published since 1969 (Figure 1A). Of the more than eight million papers indexed by BIOSIS between 1969 and 1992, 629 had the word *riparian* in either the title or the list of keywords. Only one of these papers was published in 1969; but since then, the number of riparian-related articles published per year has progressively increased, peaking in 1990 with eighty-four papers. A simple increase in the absolute number of papers published on a specific topic may say little about how society judges that topic's relative importance because the total number of scientific papers published has steadily increased since 1969. However, the relative number of riparian citations (number of riparian citations/total citations) also has increased with time, suggesting that interest in riparian ecosystems is continuing to increase (Figure 1B).

This paper provides an overview of what we know about riparian ecosystems. Specific objectives are to

1. Discuss the ecological functions that riparian ecosystems perform within the context of the surrounding landscape

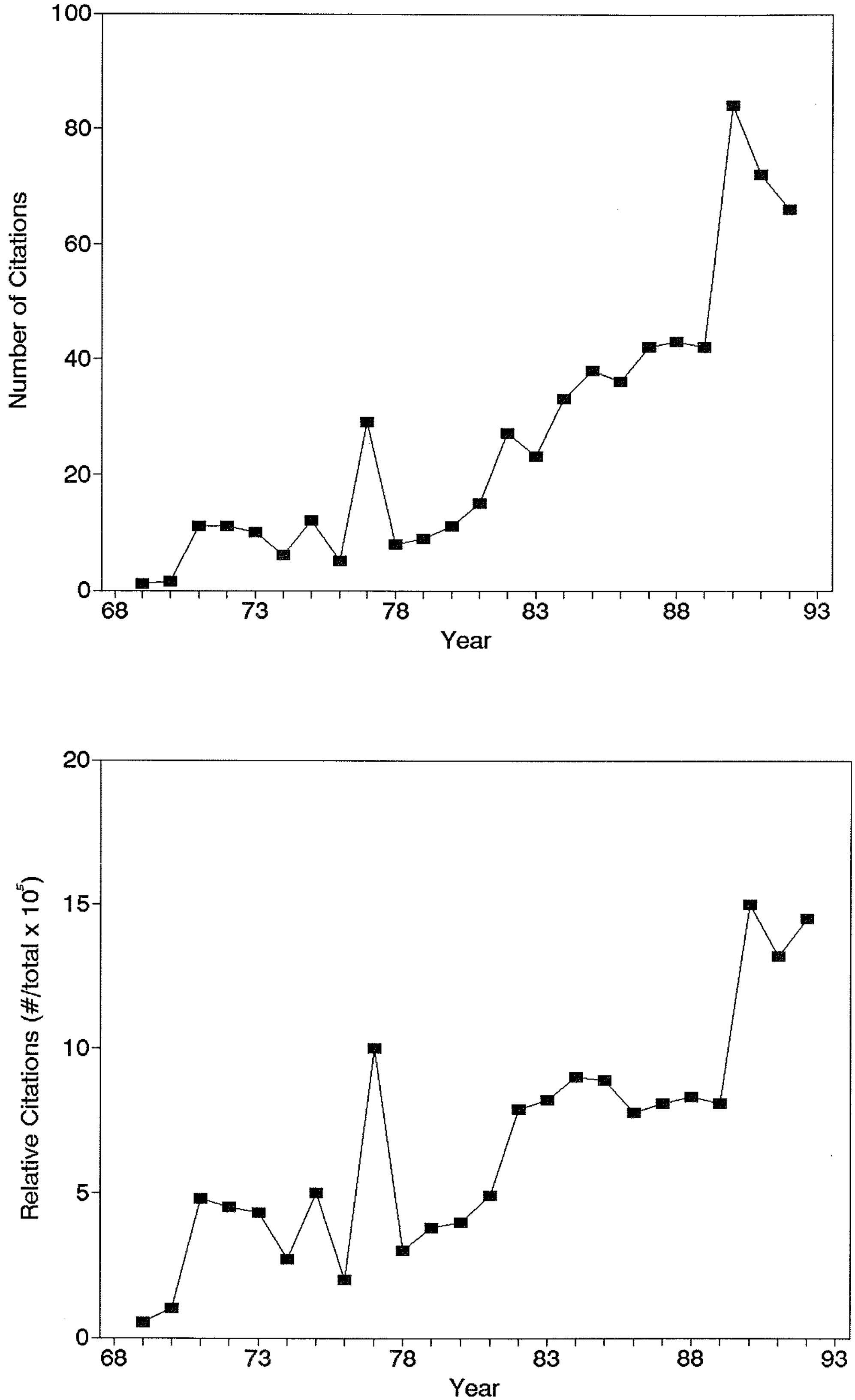

Figure 1. Number (figure 1A, top) and relative number (figure 1B, bottom) of articles indexed each year between 1969 and 1992 in BIOSIS that contained the word *riparian* in either the title or keywords. The relative number of citations was calculated as the number of riparian articles divided by the total number of articles indexed each year. Values of (B) are multiplied by 10^5 in the figure.

2. Describe how human use of riparian ecosystems depends on these functional attributes

3. Describe the extent of alteration and degradation that has occurred to riparian ecosystems within the United States

4. Illustrate some of the challenges scientists and managers face in developing an ecologically sound and operationally useful definition of a riparian ecosystem

5. Conclude by pointing to several issues that scientists and managers must address during the 1990s if they are to develop ecologically sound management practices

WHAT IS A RIPARIAN ECOSYSTEM? AN IMPRECISE DEFINITION

Nearly everyone has seen a riparian ecosystem even if he didn't recognize it. The word *riparian* is derived from the Latin *ripa*, which means riverbank. Used as a noun, the term *riparian* refers to a landowner whose property borders a stream. In the ecological literature, the term is used as an adjective to describe the location of a particular type of ecosystem.

Riparian ecosystems occur along the banks of streams. We normally, and most readily, recognize them in their unaltered state as the strips of green vegetation that occur from somewhere near water's edge outward to somewhere near the edge of the floodplain. Although vegetation is often the most conspicuous part of a riparian ecosystem, the entire ecosystem comprises a variety of life forms (microbes, plants, and animals) and abiotic environmental features that occur within a defined area.

ECOLOGICAL FUNCTIONS OF RIPARIAN ECOSYSTEMS

Riparian ecosystems are of great ecological interest because they are often functionally and structurally distinct from the upland ecosystems (e.g., forest, shrub, or grassland) that they dissect. Their ecological uniqueness is largely due to the effects of a single abiotic factor—the presence of large quantities of water. Near-stream environments are hydrologically and geomorphically dynamic in the sense that periodic flooding occurs that can scour floodplain surfaces in some areas and deposit material in others. The combination of periodic inundation and the proximity of the water table to the floodplain surface ensures that average riparian soil moisture is high relative to upland areas. Water either directly or indirectly influences all of the functional and structural attributes of riparian ecosystems.

Plant Production and Diversity

Availability of water is one of the most important conditions limiting plant growth in terrestrial environments. Because water is readily available in riparian ecosystems, plant growth may be much greater in these areas than in upland ecosystems. Differences between upland and riparian ecosystems in plant production may be especially noticeable in arid regions. For example, Reichle (1970) and Webb et al. (1983) showed that plant production in moist areas, like riparian ecosystems, was up to twenty-five times higher than that measured in drier regions.

The vegetation of riparian ecosystems also frequently exhibits high structural and taxonomic diversity (Brinson et al. 1981, Clary et al. 1992, Youngblood et al. 1985). Areas that support high plant production are often dominated by plant species that form either dense (shrubs) or high (trees) stands. Such stands are architecturally complex due to the range of sizes exhibited by different species (herbs to trees) and the branching and anastomosing growth patterns of individual plants of all sizes. Plant taxonomic diversity is also usually high due to the combined effects of readily available water and nutrients and the periodic scouring by floods that prevent potentially dominant species from monopolizing space (Day et al. 1988).

Wildlife Production and Diversity

Two ecological truisms are that (1) areas of high production at one trophic level tend to exhibit high production at higher trophic levels and (2) physical complexity tends to beget high ecological diversity. Wildlife abundance should, therefore, be correlated with plant production; and wildlife diversity should be correlated with plant structural complexity. These principles are clearly illustrated by contrasting riparian and upland areas. Average bird densities are approximately twice as high in riparian areas as they are in upland areas. Furthermore, more wildlife species use riparian areas than all other habitats combined (Brinson et al. 1981, Knopf et al. 1988). Wildlife congregate in riparian areas because these ecosystems provide abundant water, food, and shelter and provide forested corridors through which individual animals can migrate and disperse (Thomas et al. 1979).

Fish Production and Diversity

Stream systems that are surrounded by healthy riparian ecosystems also tend to have more productive and diverse fisheries than streams lacking riparian vegetation (Gregory et al. 1987, Karr and Schlosser 1977, Sedell et al. 1990). The reasons for this productivity and diversity are that riparian floodplains provide important nursery habitat for many fish species, function as a source of large woody debris (dead trees) that fish use for shelter, stabilize stream channels, and reduce summer and increase winter water temperatures. Riparian vegetation also appears to stabilize the invertebrate food base for fish by inputting organic litter into the stream during fall and winter. During this time period, algal production is usually low, and terrestrially derived litter may be the only food available to many invertebrates.

Flow Moderation and Water Storage

Riparian vegetation can reduce average water velocity and, hence, increase the length of time it takes a given volume of water to travel from an upstream to a downstream point (Elmore and Beschta 1987, Gosselink et al. 1990). During periods of flooding, the presence of vegetation acts to reduce stream efficiency and, thereby, reduces the peak stage heights of individual storms. Some of this water may be temporarily stored in floodplain soils or stored for longer periods as ground water. During periods of low flow, this stored water may be slowly released to the stream channel thereby augmenting base flows.

Water Quality

Riparian ecosystems regulate water quality in at least two ways. First, riparian vegetation decreases suspended sediment loads in streams by reducing bank erosion and by trapping sediment eroding from hillslopes (Elmore and Beschta 1987). Floodplains with abundant vegetation tend to store sediment and as a consequence have deeper soils than floodplains without vegetation. The combined effect of deeper soils and deep-rooted vegetation is to reduce the nutrient concentration of water entering the stream channel (Karr and Schlosser 1977, Lowrance et al. 1984, Whigham et al. 1988).

The shading provided by riparian vegetation also regulates water temperatures in some streams (Beschta et al. 1987). By blocking sunlight and insulating the near-stream environment, riparian vegetation can reduce summer maximum temperatures by as much as 16°C and increase winter minimum temperatures by as much as 2°C. In both cases, the daily range in temperatures is reduced.

THE VALUE OF RIPARIAN AREAS TO HUMANS

The functional attributes of riparian ecosystems just described give these areas a high value for numerous human uses (Table 1). Chief among these attributes is their potential to produce plants useful to human society. At one time, riparian ecosystems supported extensive floodplain forests. Many of these forests were harvested for their timber and converted to cropland. Now, much of this country's most productive farmland occurs on floodplains once covered with riparian forests. The agricultural productivity of these areas is sustained in part by the availability of water and by the tendency for sediment and nutrients derived from upstream or upslope areas to deposit onto low-gradient floodplains.

The potential of riparian areas has also been exploited to produce large quantities of high-quality water for both domestic and agricultural use. In many cases, the water has been diverted away from source areas for use in distant agricultural fields or cities; or reservoirs capable of storing more water than local soils and aquifers have been constructed on site.

Many riparian areas have high value as places to build residential or recreational homes. Most people wish to live in aesthetically pleasing environments, especially ones in proximity to a stream or lake. As more and more rivers have had their flows regulated by dams, the number of houses and business offices constructed within historical floodplains has greatly increased.

Human use almost always causes alteration or loss of at least part of the original ecosystem. Some uses are less damaging than others. Where riparian systems are largely intact, they provide recreational

Table 1. Ecological functions of riparian areas and their associated human uses.

Ecological Function	Associated Human Uses
Production of plant tissue	Cultivated farmland Timber production Livestock production Housing
Wildlife diversity and production	Hunting Aesthetics
Fish diversity and production	Fishing Aesthetics
Store water and moderate flow	Domestic water supply Irrigation Water for livestock
Trap and process sediment and nutrients	Domestic water supply

Table 2. Selected publications on riparian ecosystem ecology and management with emphasis on the Western U.S.

Karr and Schlosser (1977)	Johnson et al. (1985)
Johnson and Jones (1977)	Platts et al. (1987)
Johnson and McCormick (1978)	Salo and Cundy (1987)
Cope (1979)	General Accounting Office (1988)
Cowardin et al. (1979)	Abell (1989)
Brinson et al. (1981)	Gresswell et al. (1989)
Swanson et al. (1982)	Minshall et al. (1989)
Anderson et al. (1982)	Mereszczak et al. (1990)
Warner and Hendrix (1984)	Gregory et al. (1991)
Youngblood et al. (1985)	

opportunities for hunters, fishermen, hikers, and naturalists. In some cases, however, even recreational use can alter the potential of an area to support certain ecological functions. An example is excessive camping and travel within the floodplain, reducing vegetation and wildlife.

LOSS AND DEGRADATION OF RIPARIAN ECOSYSTEMS

The uses described above have contributed to a startling loss of riparian ecosystems within the United States and other countries. Based on data in Brinson et al. (1981), most of the alteration to riparian ecosystems appears to occur within 100 years of settlement by nonaboriginal peoples (Figure 2). In the United States, up to 98 percent of the riparian ecosystems that existed prior to European colonization have been lost or significantly altered (Brinson et al. 1981, Swift 1984). Considering that riparian areas originally represented less than 2 percent of the overall landscape, the significance of these losses for wildlife, fisheries, plant species diversity, and water quality is profound. Of particular concern is that many riparian ecosystems may have become so small and fragmented that they will be unable to maintain viable populations of many plant and animal species on a long-term basis (Harris 1984, Harris 1988).

RESPONSE TO THE PROBLEM

The recognition that most of the original riparian ecosystems have been profoundly altered has initiated a strong response from the scientific community and resource-management agencies. Since about 1977, nineteen major symposiums or syntheses have been published describing the status, ecological properties of, or management of riparian ecosystems (Table 2). These studies have greatly advanced the understanding of the structural and functional properties of riparian ecosystems, although the greater task of first reducing and then reversing the ongoing destruction remains largely unaddressed.

IS A STANDARD DEFINITION OF *RIPARIAN ECOSYSTEM* NEEDED OR POSSIBLE?

As is true for most other ecosystems, it is difficult to provide an unambiguous and conceptually comprehensive definition of a riparian ecosystem that is both ecologically complete and operationally useful. There are three main reasons why a universally accepted definition has not emerged to date. First, ecosystems are seldom, if ever, discrete entities with clearly defined spatial boundaries. Most ecosystems grade into one another, and what we usually refer to as boundaries are areas where physicochemical gradients are steepest. For some riparian ecosystems (e.g., those in V-shaped valleys), gradients between the floodplain and hillslopes may be so steep that for all practical purposes discrete boundaries do exist. In areas of gradual topographic relief, however, the transition from one environmental complex to the next may occur over several and even hundreds of meters. Delineating boundaries in these cases is largely an arbitrary decision.

A second and equally difficult problem is that individuals may not agree on the functional and structural criteria on which to base a definition. For example, if one person emphasizes the presence of a certain type of vegetation and another weights the extent to which nutrients move among adjacent areas, these two people would almost certainly draw different boundaries. This problem is so fundamental that MacMahon et al. (1978) argue that the definition of an ecosystem should depend mainly on the question being asked, i.e., the concept itself is investigator dependent.

The problem is further confounded by the fact that scientists usually want as ecologically encompassing a definition as possible, whereas resource managers strive for a definition that can be easily applied under a wide variety of field conditions. To illustrate the extent of the problem, three of the definitions in use today follow:

Gregory et al. (1991:540) defined riparian ecosystems from a functional perspective as the "three-dimensional zones of direct interaction between terrestrial and aquatic ecosystems. . . . Boundaries of riparian zones extend outward to the limits of flooding and upward into the canopy of streamside

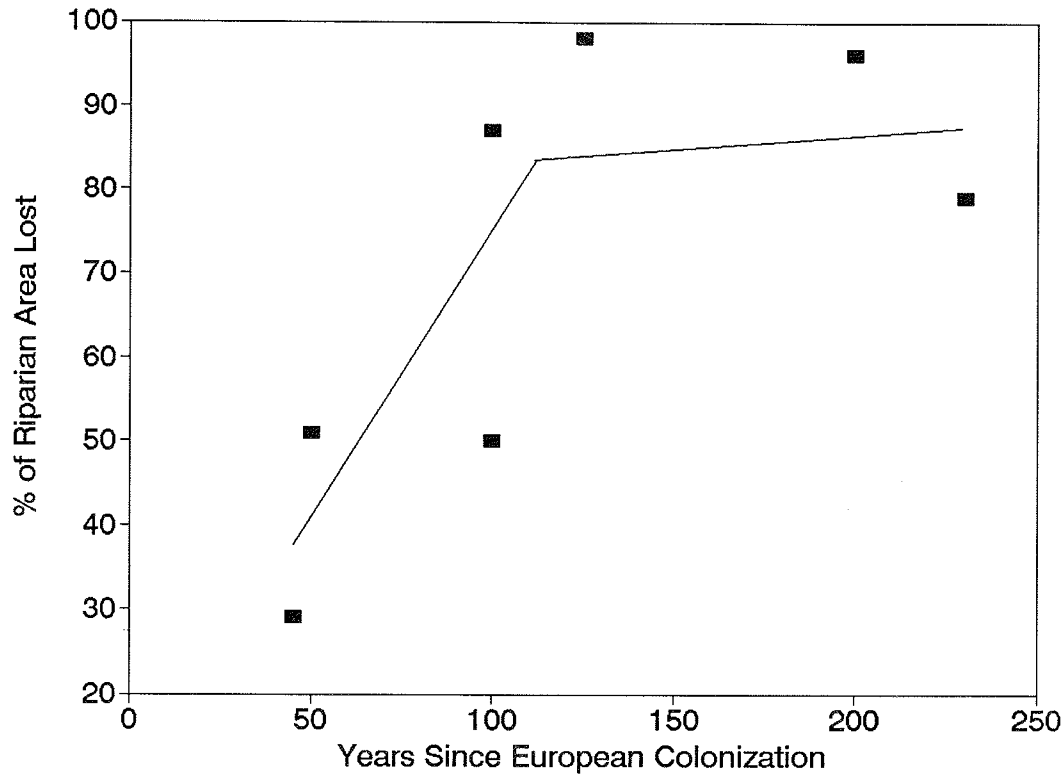

Figure 2. Loss of riparian area as a function of time in years since European colonization. Data points represent different major riparian ecosystems within the United States and were extracted from Brinson et al. (1981).

vegetation."

Cowardin et al. (1979) described riparian areas as one type of wetland and defined wetlands as (p. 3) "lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered with shallow water. For purposes of this classification, wetlands must have one or more of the following three attributes: (1) at least periodically, the land predominantly supports hydrophytes, (2) the substrate is predominately undrained hydric soil, and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year."

Cowardin et al. (1979) further defined riparian, i.e., palustrian, wetlands to include (p. 10) "all nontidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5 percent. The definition also includes wetlands lacking vegetation but with all of the following four characteristics: (1) areas less than 8 ha (20 acres); (2) active wave-formed or bedrock shoreline features lacking; (3) water depth in the deepest part of basin less than 2 m at low water; and (4) salinity due to ocean-derived salts less than 0.5 percent." In general, under this definition the riparian ecosystem is bounded on the aquatic side by areas that can support emergent aquatic vegetation and on the upland side by the high water line.

Federal agencies have attempted to apply a uniform standard for delineating wetland boundaries (Federal Interagency Committee for Wetland Delineation 1989) that is based on the definition of a wetland the U.S. Corps of Engineers uses when issuing permits for discharge of dredge and fill into wetlands (Section 404 (b)(1) of the Clean Water Act of 1977). Under this definition, wetlands include "areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support . . . a prevalence of vegetation typically adapted for life in saturated soil conditions."

Although this definition goes far toward development of a standard that could be applied to riparian ecosystems as well as to other types of wetlands, its practical use is limited by (1) ambiguities regarding what constitutes "typically adapted" vegetation, (2) a poorly developed database describing the frequency and duration of saturation needed to support the hundreds of different species of wetland plants, and (3) the difficulty inherent in establishing how frequently and for how long soils are either inundated or saturated. As a consequence, the two federal agencies responsible for managing most of the riparian ecosystems in the Western U.S. (the Bureau of Land Management and the Forest Service) often use guidelines that reflect local conditions or the particular biases of local riparian-resource personnel.

THE CHALLENGES AHEAD

As we move into the twenty-first century, we will be severely challenged to develop ways to sustain the ecological function of our remaining riparian ecosystems and, hence, their value to both human society and the world's wildlife. To manage these ecosystems intelligently requires that we address at least five general issues about which we presently know very little:

1. We need a *functionally* useful classification scheme of riparian ecosystems. This classification should be based, in large part, on the potential of specific riparian ecosystems to support different uses and the sensitivity of different systems to both natural and human disturbance.

2. We need a much better understanding of the role natural disturbance plays in influencing both structural and functional properties of these ecosystems. Because of their intimate connection to streams, these systems are naturally extremely dynamic. In what ways do different natural disturbances affect riparian areas, and what factors control the rate of ecosystem recovery following disturbance?

3. We need to quantify how different human uses affect dysfunction, especially in context of the effects of natural disturbance.

4. We quickly need objective data from which we can prioritize efforts to conserve extant systems. These data would include information on the size of different remaining fragments, their location within the overall landscape, their proximity to other types of ecosystems, the specific type of system in terms of taxonomic composition and functional attributes, and the uses they presently sustain.

5. We must develop ways to restore many of our currently degraded riparian areas. The loss of riparian ecosystems has been so great that conservation and preservation of the remaining areas is insufficient to ensure the persistence of these systems. This challenge is especially daunting for areas associated with large rivers. The costs of restoration will almost certainly be high. It is, therefore, important that the effectiveness of current restoration practices be rigorously evaluated. Considering the chances that an "engineered" fix may cause more damage than good in these dynamic systems, any proposed restoration practice should be evaluated in terms of what it will do, and how quickly it will do it, relative to natural recovery processes.

REFERENCES

Abell, D. L., ed. 1989. Proceedings of the California riparian systems conference: Protection, management, and restoration for the 1990s. September 22–24, 1988. Davis, Calif. U. S. Department of Agriculture, Forest Service General Technical Report PSW-110, Berkeley, Calif.

Anderson, A., G. Haugen, D. Duff, G. Taylor, D. Albin, D. Erman, D. Reiser, M. Bacon, T. Jackson, K. Overton, C. McAucliff, J. Griffith, and J. Cooper. 1982. The best management practices for the management and protection of Western riparian stream ecosystems. American Fisheries Society, Western Division.

Beschta, R. L., R. E. Bilby, G. W. Brown, L. B. Holtby, and T. D. Hofstra. 1987. Stream temperature and aquatic habitat: Fisheries and forestry interactions. Pages 191–232 *in* E. O. Salo and T. W. Cundy, eds. Streamside management: Forestry and fishery interactions. February 12–14, 1986. Seattle, Wash. Contribution (University of Washington, Institute of Forest Resources) No. 57. College of Forest Resources, University of Washington, Seattle.

Brinson, M. M., B. L. Swift, R. C. Plantico, and J. S. Barclay. 1981. Riparian ecosystems: Their ecology and status. U. S. Department of the Interior, Fish and Wildlife Service, Office of Biological Services FWS/OBS-81/17, Kearneysville, W. Va.

Clary, W. P., E. D. McArthur, D. Bedunah, and C. L. Wambolt, eds. 1992. Proceedings—symposium on ecology and management of riparian shrub communities. May 29–31, 1991. Sun Valley, Idaho. U. S. Department of Agriculture, Forest Service General Technical Report INT-289, Ogden, Utah.

Cope, O. B., ed. 1979. Proceedings of the forum—grazing and riparian/stream ecosystems. Trout Unlimited, Denver, Colo.

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Department of the Interior, Fish and Wildlife Service, Office of Biological Services FWS/OBS-79/31, Washington, D.C.

Day, R. T., P. A. Keddy, J. McNeill, and T. Carleton. 1988.

Fertility and disturbance gradients: A summary model for riverine marsh vegetation. Ecology 69(4): 1044–54.

Elmore, W., and R. L. Beschta. 1987. Riparian areas: Perceptions in management. Rangelands 9(6): 260–65.

Federal Interagency Committee for Wetland Delineation. 1989. Federal manual for identifying and delineating jurisdictional wetlands: An interagency cooperative publication. U. S. Army Corps of Engineers, U. S. Environmental Protection Agency, U. S. Fish and Wildlife Service, and U. S. Soil Conservation Service, Washington, D.C.

General Accounting Office. 1988. Public rangelands: Some riparian areas restored but widespread improvement will be slow. GAO/RCED-88-105, Washington, D.C.

Gosselink, J. G., B. A. Touchet, J. Van Beek, and D. Hamilton. 1990. Bottomland hardwood forest ecosystem hydrology and the influence of human activities: The report of the hydrology workgroup. Pages 347–87 *in* J. G. Gosselink, L. C. Lee, and T. A. Muir, eds. Ecological processes and cumulative impacts: Illustrated by bottomland hardwood wetland ecosystems. Lewis Publishers, Chelsea, Mich.

Gregory, S. V., G. A. Lamberti, D. C. Erman, K. V. Koski, M. L. Murphy, and J. R. Sedell. 1987. Influence of forest practices on aquatic production. Pages 233–56 *in* E. O. Salo and T. W. Cundy, eds. Streamside management: Forestry and fishery interactions. February 12–14, 1986. Seattle, Wash. Contribution (University of Washington, Institute of Forest Resources) No. 57. College of Forest Resources, University of Washington, Seattle.

Gregory, S. V., F. J. Swanson, W. A. McKee, and K. W. Cummins. 1991. An ecosystem perspective of riparian zones. BioScience 41(8): 540–51.

Gresswell, R. E., B. A. Barton, and J. L. Kershner, eds. 1989. Practical approaches to riparian resource management: An educational workshop. May 8–11, 1989. Billings, Mont. U. S. Department of the Interior, Bureau of Land Management BLM-MT-PT-89-001-4351.

Harris, L. D. 1984. The fragmented forest: Island biogeography theory and the preservation of biotic diversity. University of Chicago Press, Chicago, Ill.

Harris, L. D. 1988. The nature of cumulative impacts on biotic diversity of wetland vertebrates. Environmental Management 12(5): 675–93.

Johnson, R. R., and D. A. Jones, tech. coords. 1977. Importance, preservation and management of riparian habitat: A symposium. July 9, 1977. Tuscon, Ariz. U. S. Department of Agriculture, Forest Service General Technical Report RM-43, Fort Collins, Colo.

Johnson, R. R., and J. F. McCormick, tech. coords. 1978. Strategies for the protection and management of floodplain wetlands and other riparian ecosystems: Proceedings of the symposium. December 11–13, 1978. Callaway Gardens, Ga. U.S. Department of Agriculture, Forest Service General Technical Report WO-12, Washington, D. C.

Johnson, R. R., C. D. Ziebell, D. R. Patton, P. F. Ffolliott, and R. H. Hamre, eds. 1985. Riparian ecosystems and their management: Reconciling conflicting uses. April 16–18, 1985. Tucson, Ariz. U. S. Department of Agriculture, Forest Service General Technical Report RM-120, Fort Collins, Colo.

Karr, J. R., and I. J. Schlosser. 1977. Impact of nearstream vegetation and stream morphology on water quality and stream biota. Office of Research and Development, Environmental Protection Agency, Environmental Research Laboratory EPA-600/3-77-097, Athens, Ga.

Knopf, F. L., R. R. Johnson, T. Rich, F. B. Samson, and R. C. Szaro. 1988. Conservation of riparian ecosystems in the United States. Wilson Bulletin 100(2): 272–84.

Lowrance, R., R. Todd, J. Fail, Jr., O. Hendrickson, Jr., R. Leonard, and L. Asmussen. 1984. Riparian forests as nutrient filters in agricultural watersheds. BioScience 34(6): 374–77.

MacMahon, J. A., D. L. Phillips, J. V. Robinson, and D. J. Schimpf. 1978. Levels of biological organization: An organism-centered approach. BioScience 28(11): 700–704.

Mereszczak, I., J. Colmer, J. Oden, J. Almy, M. Hoppus, P. J. Ishikawa, H. Lachowski, J. Ward, and A. J. Oslin. 1990. Riparian area management: What can remote sensing contribute? U.S. Department of Agriculture, Forest Service, Engineering Staff EM 7140-19, Washington, D.C.

Minshall, G. W., S. E. Jensen, and W. S. Platts. 1989. The ecology of stream and riparian habitats of the Great Basin region: A community profile. U. S. Department of the Interior, Fish and Wildlife Service Biological Report 85(7.24), Slidell, La.

Platts, W. S., C. Armour, G. D. Booth, M. Bryant, J. L. Bufford, S. Jensen, G. W. Lienkaemper, G. W. Minshall, S. B. Monsen, R. L. Nelson, J. R. Sedell, and J. S. Tuhy. 1987. Methods for evaluating riparian habitats with applications to management. U. S. Department of Agriculture, Forest Service INT-221, Ogden, Utah.

Reichle, D. E. 1970. Analysis of temperate forest ecosystems. Springer-Verlag, New York.

Salo, E. O., and T. W. Cundy, eds. 1987. Streamside management: Forestry and fishery interactions. February 12–14, 1986. Seattle, Wash. Contribution (University of Washington, Institute of Forest Resources) No. 57. College of Forest Resources, University of Washington, Seattle.

Sedell, J. R., G. H. Reeves, F. R. Hauer, J. A. Stanford, and C. P. Hawkins. 1990. Role of refugia in recovery from disturbances: Modern fragmented and disconnected river systems. Environmental Management 14(5): 711–24.

Swanson, F. J., S. V. Gregory, J. R. Sedell, and A. G. Campbell. 1982. Land-water interactions: The riparian zone. Pages 267–91 *in* R. L. Edmonds, ed. Analysis of coniferous forest ecosystems in the Western United States. Hutchinson Ross Publishing, Stroudsburg, Pa.

Swift, B. L. 1984. Status of riparian ecosystems in the United States. Water Resources Bulletin 20(2): 223–28.

Thomas, J. W., C. Maser, and J. E. Rodiek. 1979. Riparian zones in managed rangelands: Their importance to wildlife. Pages 21–31 *in* O. B. Cope, ed. Proceedings of the forum—grazing and riparian/stream ecosystems. November 3–4, 1978. Trout Unlimited, Denver, Colo.

Warner, R. E., and K. M. Hendrix. 1984. California riparian systems: Ecology, conservation, and productive management. University of California Press, Berkeley.

Webb, W. L., W. K. Lauenroth, S. R. Szarek, and R. S. Kinerson. 1983. Primary production and abiotic controls in forests, grasslands, and desert ecosystems in the United States. Ecology 64(1): 134–51.

Whigham, D. F., C. Chitterling, and B. Palmer. 1988. Impacts of freshwater wetlands on water quality: A landscape perspective. Environmental Management 12(5): 663–71.

Youngblood, A. P., W. G. Padgett, and A. H. Winward. 1985. Riparian community type classification of eastern Idaho-western Wyoming. U. S. Department of Agriculture, Forest Service R4-Ecol-85-01.