Riparian Restoration in the Western United States: Overview and Perspective

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Abstract

This historical and conceptual overview of riparian ecosystem restoration discusses how riparian ecosystems have been defined, describes the hydrologic, geomorphic, and biotic processes that create and maintain riparian ecosystems of the western USA, identifies the main types of anthropogenic disturbances occurring in these ecosystems, and provides an overview of restoration methods for each disturbance type. We suggest that riparian ecosystems consist of two zones: Zone I occupies the active floodplain and is frequently inundated and Zone II extends from the active floodplain to the valley wall. Successful restoration depends on understanding the physical and biological processes that influence natural riparian ecosystems and the types of disturbance that have degraded riparian areas. Thus we recommend adopting a process-based approach for riparian restoration. Disturbances to riparian ecosystems in the western USA result from streamflow modifications by dams, reservoirs, and diversions; stream channelization; direct modification of the riparian ecosystem; and watershed disturbances. Four topics should be addressed to advance the state of science for restoration of riparian ecosystems: (1) interdisciplinary approaches, (2) a unified framework, (3) a better understanding of fundamental riparian ecosystem processes, and (4) restoration potential more closely related to disturbance type. Three issues should be considered regarding the cause of the degraded environment: (1) the location of the causative disturbance with respect to the degraded riparian area, (2) whether the disturbance is ongoing or can be eliminated, and (3) whether or not recovery will occur naturally if the disturbance is removed.

Introduction

Riparian ecosystems support many critically important ecological functions within western landscapes (Brinson et al. 1981), but most riparian areas have been severely degraded by a variety of human disturbances (NRC 1992). Restoration—returning an ecosystem to its original condition—is being used more often to mitigate some of the past degradation of these ecosystems, and many examples of restoration efforts are now available. Although the science of riparian restoration is young and undeveloped, progress is being made. The articles in this volume describe some of the new ideas being developed and applied to the restoration of riparian ecosystems in the western United States. This article offers a historical and conceptual overview of the present status of riparian restoration and provides context for the articles that follow.

In a previous review of literature on wetland restoration in the western USA, Manci (1989) found only 92 articles on riparian ecosystems out of 1,000 articles on the creation or restoration of various wetland types. Seventy-four percent (68/92) of these articles were published in the 1980s. However, we suspect this review excluded much relevant literature, because important riparian restoration studies have been published within the context of stream enhancement, stream management, or instream flow mitigation. We conducted a broad search that included these descriptors in addition to the keywords *riparian restoration* and *riparian creation*. That search yielded over 400 articles published between 1970 and 1995 (Fig. 1) relevant to western riparian restoration issues. Even though the graph (Fig. 1) does not include individual contributions in symposium proceedings, it is clear that interest in riparian issues has grown rapidly since 1970, a trend that parallels interest in the general ecology and management of riparian ecosystems (Hawkins 1994). A review of the literature compiled during our expanded search provided the basis for this overview. We examine the nature and diversity of riparian ecosystems, with an emphasis on the

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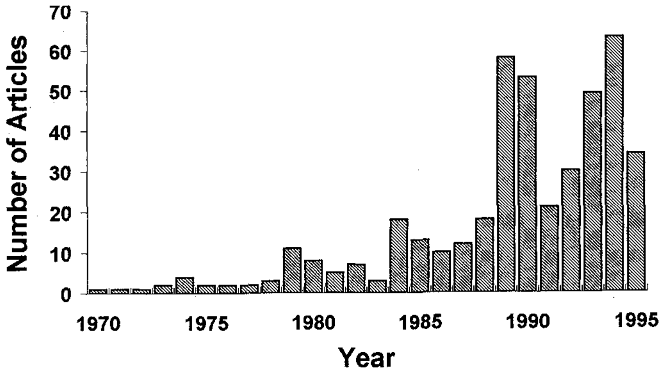

Figure 1. Number of papers or books published each year between 1970 and 1995 addressing some aspect of riparian restoration. Citations were obtained by searching the following CD-ROM bibliographic data bases: AGRICOLA (1970–Present), Environmental Periodicals Bibliography (1972–Present), Fish and Fisheries (1971–Present), GEOREF (1785–Present), and Water Resources Abstracts (1967–Present).

western USA, the types of anthropogenic disturbances to riparian systems that have led to the need for restoration, and the conceptual and practical issues that define the present state of riparian restoration science.

What are Riparian Ecosystems?

Definitions. It is difficult to apply a single definition to all riparian ecosystems. Several authors have offered definitions (e.g., Cowardin et al. 1979; Brinson et al. 1981; Gregory et al. 1991; Malanson 1995), and most definitions are similar in general concept. All definitions differ, however, in the specific criteria used to define both the boundary between riparian and upland ecosystems and the different zones that may exist within riparian ecosystems. We believe the utility of a definition rests on its applicability to specific management or research objectives. It may therefore be undesirable and perhaps impossible to provide a general definition satisfactory to all. For this article, we believe a definition similar to those offered by Kovalchik & Chitwood (1990), Gregory et al. (1991), and Malanson (1995) provides a useful framework for understanding the structural and functional components of riparian ecosystems.

In the western USA, riparian ecosystems are the narrow ecotones between aquatic and terrestrial ecosystems that consist of several fluvial surfaces, including channel islands and bars, channel banks, floodplains, and lower terraces (Fig. 2a). This definition includes those areas directly influenced by frequent flooding (Zone I) and areas adjacent to a river that were formed by past fluvial action, but which are generally not currently influenced by fluvial processes (Zone II). Together, these two zones constitute the valley floor. Zone I occurs on moist, lower, more frequently flooded surfaces. Zone II, occurring on inactive floodplains and higher terrace surfaces, is drier and less subject to flooding. These two zones are not always present in all sections of a river corridor (e.g., canyons; Fig. 2b) and the separation between them is not always distinct, often existing along a continuum rather than as a sharp boundary. However, dividing riparian ecosystems into these two zones helps differentiate among the structural and functional properties of the varied surfaces

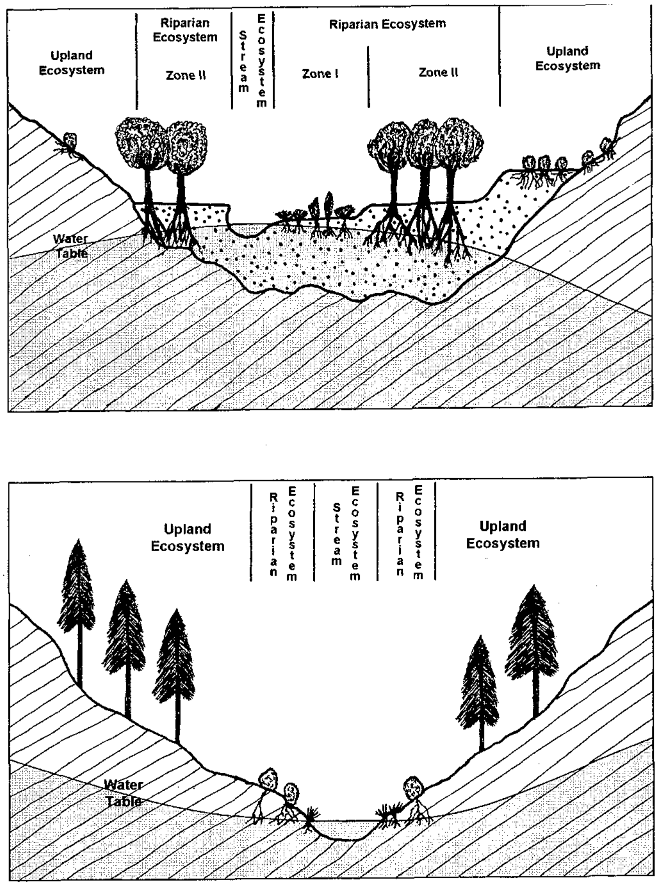

Figure 2. Above. Simplified scheme illustrating the geomorphic and ecological structure of a riparian ecosystem comprised of two zones. Zone I areas are frequently inundated, subject to current-day fluvial geomorphic processes, and are at elevations that allow shallow-rooted plants to extract water from the water table. Zone II represents areas that were formed by past fluvial geomorphic processes and are higher in elevation than surfaces in Zone I, and in which vegetation is dominated by deeply-rooted plants capable of extracting water from the underlying alluvial aquifer. Below. Canyon stream in which the riparian area is a narrow band along either side of the stream. Zones I and II do not exist in this situation.

occurring within riparian ecosystems, as the following discussion illustrates.

Areas in Zone I are intimately linked to stream ecosystems, and the two ecosystems exchange energy and matter. The exchange of energy and matter in Zone II is largely unidirectional, with Zone II providing material and affecting energy inputs to both Zone I and the stream ecosystem. Although Zone II is not strongly influenced by geomorphic processes of the stream, past fluvial actions appear to have been necessary for the establishment of the vegetation occupying this zone. In addition, shallow depth to alluvial groundwater in Zone II allows domination by phreatophytic species, which derive their water supply from the saturation zone and which cannot survive in upland areas where groundwater depth is greater (Fig. 2a). We therefore consider Zone II an important part of riparian ecosystems.

Genesis, Process, and Form. Understanding the processes that create and maintain riparian ecosystems is critical to planning successful restoration projects. Two main processes operate to create riparian ecosystems, both of which depend on regional climatic conditions: hydrogeomorphic processes and biotic change (Fig. 3).

Streamflow is the primary mechanism that shapes near-stream landforms. Zone I surfaces typically are constructed by depositional processes operating at the present river level and under current hydrologic conditions. These processes occur rather frequently (Wolman & Miller 1960). However, episodic floods of large magnitude can dramatically alter river floodplains through channel downcutting or widening (Schumm & Lichty 1963; Burkham 1972; Baker 1977; Wolman & Gerson 1978; Hereford 1993; Friedman et al. 1996). A major flood can destroy an existing riparian ecosystem, which may then take decades to reestablish itself, depending on regional climatic conditions (Wolman & Gerson 1978). These observations have led to two ideas: (1) some western floodplains may oscillate between eroded and non-eroded states (Nanson & Croke 1992) and (2) the structure of many western stream channels and their floodplain riparian zones may largely represent legacies of past catastrophic disturbances, not a state in quasi-equilibrium with the annual flood regime (Graf 1979, 1983). The degree to which riparian ecosystems are structured by episodic or annual floods has significant consequences for how we think about and approach stream and riparian zone restoration.

Denuded or new fluvial surfaces provide a physical template on which specific plant associations develop (Fig. 3). For example, *Populus* spp. (cottonwood trees) establish on fresh sediment deposits generated during flood flows (Bradley & Smith 1985; Scott et al. 1996). Site-specific differences in vulnerability to floods, time since disturbance, and groundwater conditions can create temporally and spatially variable plant associations on otherwise similar fluvial surfaces. Biotic change can also alter the overall character of riparian landforms and stream channels by physically altering the floodplain and stream channel (Bleed 1987). Once plants are established, vegetation generally encroaches toward the active stream, stabilizing near-stream surfaces and stream banks. Because vegetated surfaces resist erosion, much of the work of flowing water is directed vertically into the stream channel, and the channel becomes narrower and deeper.

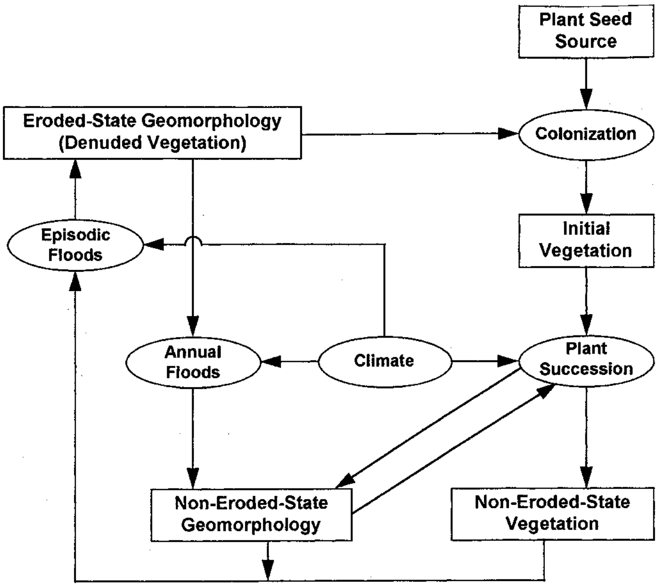

Figure 3. A conceptual diagram illustrating the fluvial and ecological processes that interact to form riparian landscapes. Arrows represent causal pathways by which geomorphic conditions or vegetation (boxes) are altered by physical or biological processes (ovals). See text for detailed explanations.

A characteristic most western riparian ecosystems have in common is that they are distinct from upland areas with respect to vegetation, because of the greater availability of water in an otherwise water-limited landscape (Fisher 1995). Water availability is the single most important factor controlling the growth of riparian vegetation (Brinson et al. 1981; Kovalchik & Chitwood 1990; Hupp & Osterkamp 1996). In general, the biomass and species composition of riparian vegetation varies with increasing distance from and elevation above the river (Kovalchik & Chitwood 1990). The current-day floodplain (Zone I) typically is occupied by herbaceous species, willows or other shrubs, and cottonwoods. The first terrace above the active floodplain (part of Zone II) is often dominated by cottonwood trees (Leopold & Miller 1954; Hereford 1984) or other large phreatophytic trees.

State of the Science by Anthropogenic Disturbance Type

Background. Documented attempts at riparian ecosystem restoration appear to be limited primarily to the past 20 to 25 years (Fig. 1), a time that coincides with the environmental movement of the late 1960s to early 1970s and the passage of environmental legislation, including the National Environmental Policy Act (1969), Clean Water Act (1972), and Endangered Species Act (1973). Through the early 1970s, many human actions that created the need for restoration of riparian ecosystems were still occurring. Today, many of these activities have been halted or reduced, and the challenge is now one of restoring past losses or providing mitigation for activities likely to result in additional aquatic, riparian, or wetland losses.

Our literature review revealed one obvious fact: there have been few true restorations, if restoration is defined as reestablishment of predisturbance functions and related physical, chemical, and biological characteristics (NRC 1992). Many enhancements have been undertaken to lessen the ecosystem damages caused by past land management practices. Rehabilitations and reclamations have been undertaken to fix some but not all aspects of degraded environments. In many cases, restoration has not been possible due to ongoing anthropogenic disturbances, but attempts have been made to lessen the ongoing effects with more environmentally sound management.

A key aspect of riparian ecosystem restoration is that it often cannot be divorced from stream restoration, though the opposite has not always been true. Many stream restorations have been undertaken specifically to enhance fisheries by reestablishing aquatic habitat (Gore 1985). One can readily find examples of stream restorations that never explicitly mention the riparian ecosystem (e.g., Barton & Winger 1973; Newbury 1995).

One facet of the riparian restoration problem is that there is not, and probably never will be, a universal approach appropriate for all situations. The continuum of river and riparian environments is so extensive as to prevent universal solutions, and transferring approaches based on relations and concepts developed for one river corridor to another must be undertaken with caution (Schumm 1984). Still, commonalities exist among river and riparian systems, and later in this article we propose a means for uniting riparian restoration ideas under a common framework.

Understanding how to restore specific riparian systems requires that we recognize the specific disturbances that have altered a system. We have organized this part of our discussion by the type of anthropogenic disturbances that have affected western riparian ecosystems. Generally, specific human disturbances generate a distinct set of effects, although these effects may manifest themselves differently in different fluvial and riparian environments. Several types of human disturbance are of greater concern for western riparian zones than elsewhere. Water development, channelization, and agriculture have severely affected many low elevation riparian ecosystems, whereas higher elevation systems have been affected by grazing, logging, and mining. In contrast, relatively little of the western landscape has been urbanized.

Dams, Reservoirs, and Diversions. Modifications to streamflow by dams and diversions have significantly affected riparian ecosystems, particularly in the western USA (Ligon et al. 1995; Smith et al. 1991). Because of the aridity of the West, development of the region's water resources has been essential to agriculture, urban population growth, and industrial development. Also, geologic uplift and subsequent river erosion have created deep canyons that have facilitated construction of major hydropower facilities. Due to lesser streamflows and large storage capacity, a higher percentage of streamflow is stored in reservoirs in the West compared to the eastern USA. For example, the ratio of reservoir storage capacity to annual water supply is 2.32 for the Colorado River basin and 1.19 for the Missouri River basin (Hirsch et al. 1990). For the eastern USA, this ratio ranges from about 0.1 to 0.3 (Hirsch et al. 1990). Thus, reservoir effects upon riparian conditions should be expected to be more significant for the western USA than for the eastern USA.

Substantial effects on riparian ecosystems usually occur downstream of a dam, with these effects sometimes persisting for hundreds of kilometers downstream. The primary purpose of a reservoir is to stabilize the flow of water, either by varying a supply of natural streamflow or by satisfying a varying demand (Linsley et al. 1992). In the West, this typically means storing the springtime snowmelt flood runoff for release in the summer of the same year or in a later low-flow year. Williams and Wolman (1984) showed that below 29 western dams, the mean annual floods decreased an average of 40 percent from the values recorded before existence of the dams.

Effects of dam regulation upon the downstream riparian ecosystem may include a decrease in magnitude and frequency of downstream floods, changes in sediment loads, channel degradation, channel aggradation, or changes in the size and shape of the channel (Williams & Wolman 1986). The precise changes downstream are difficult to predict and depend upon channel geomorphology, streamflow hydrology, and reservoir operation. Scott et al. (1996) suggest that three processes—channel narrowing, channel meandering, and flood-related sediment deposition—may be responsible for the establishment of bottomland woodlands. Because different processes predominate along different river reaches, the effects of a dam vary at locations along a river or between rivers. For example, expansion of the riparian forest has taken place along the North Platte River in Nebraska as a result of dam regulation of streamflows (Williams 1978). Below many western dams, however, riparian forests are in decline (Rood & Mahoney 1990). As Williams and Wolman (1986) note, the environmental effects downstream from a dam may be favorable, unfavorable, or insignificant.

Some solutions have been introduced to counter the effects of dams and diversions. Hill et al. (1991) suggested riparian maintenance flows similar to channel maintenance flows. Others (Auble et al. 1994; Hill et al. 1991; Risser & Harris 1989; Rood & Mahoney 1990; Stromberg & Patten 1990) are providing research needed to quantify the necessary flow regimes for critical species. Model approaches have been proposed to give guidance for restoration flow regimes (Mahoney & Rood 1993; Auble et al. 1994). Although much has yet to be learned, progress is being made to quantify the flow requirements of riparian ecosystems.

Providing a proper riparian maintenance flow regime may be a political-social-economic problem rather than a technical one. Water being stored in a reservoir or diverted from a stream is legally appropriated for beneficial use under the appropriative doctrine ("first in time, first in right") common to western states (Bates 1993). Many western states have amended their laws to provide for appropriation of water for instream-flow beneficial uses, but such water right filings can seldom provide solutions to existing reservoir-related problems, because these most recent water rights will always be junior to existing reservoir and diversion rights. In many cases, restoring water may be the simple solution to western riparian ecosystem restoration. Unfortunately, restoring some semblance of a natural streamflow regime will not be an easy solution.

Stream Channelization. Channelization refers to human efforts to widen, deepen, and often straighten stream channels. Stream channelizations have imposed some of the greatest disturbances to river and riparian ecosystems around the world, with many such disturbances in Europe dating back centuries (Brookes 1988). Channelizations have been undertaken to provide navigable waterways, more efficient flood conveyance, and land drainage. Much of the concerted channelization effort in the USA has been concentrated in the southern and Midwestern states (Schoof 1980). In the west, stream channelization projects have affected fewer riparian areas than have water projects, grazing, and land clearance for agriculture (Swift 1984). Generally, stream channelization and straightening in conjunction with riparian vegetation removal have been used to provide flat, farmable land near river's edge, with flood control channelization being a greater issue in urban areas. Channelization accelerated from the 1940s to the 1960s, and apparently still continues in isolated locations.

Although the effects of channelization on the channel and stream ecosystem are substantial and obvious, the effects on the riparian ecosystem may be as significant. The effects of channelization on the riparian zone include reduction in frequency of floodplain inundation, reduction or elimination of natural channel migration, elimination of sediment beds used as plant recruitment areas, and lower groundwater tables. Confinement of flood flows to the channel eliminates the periodic inundation of the floodplain, and thereby decreases the level of soil moisture in the riparian zone. In meandering channels, stabilizing and fixing a channel in place eliminates point bar development and growth. Point and other channel side bars provide open areas of bare sediment available for recruitment by bottomland trees (Bradley & Smith 1985; Scott et al. 1996). Elimination of flooding and sediment deposition in areas above the channel may reduce recruitment areas in confined valleys (Scott et al. 1996). Finally, channel shortening and steepening may cause the alluvial water table to drop, turning groundwater-dependent riparian ecosystems into drier upland types (Schoof 1980; Groeneveld & Griepentrog 1985).

A primary question in the restoration of channelized reaches is whether the human disturbance can be eliminated. There may be either socioeconomic or technical reasons preventing restoration. A transformation of a natural stream to a flood channel that has allowed occupation of the floodplain riparian zone may of necessity be a permanent change. An efficient flood channel may also be the only alternative for an urban area where an undersized flood corridor must convey the larger flood flows resulting from the urbanization. In these cases, it may be impossible to remove the stressor since the channel has been engineered for long-term stability. Thus, practices to reduce, rather than eliminate, the channelization disturbance must be undertaken (Henderson 1986; Brookes 1988).

Where restoration is possible, stream restoration and riparian restoration are obviously closely linked. Fluvial geomorphologists took an early lead in stream restoration research in this area (Keller 1976; Nunnally 1980; Nunnally & Keller 1979; Brookes 1987, 1988). Stream restoration generally consists of reestablishing both a stream channel in quasi-equilibrium and a functional floodplain (Morris 1995). The channel is typically sized to convey a 1.5-year to 2-year flood discharge with higher flows spreading onto the floodplain. Channel characteristics are often selected on the basis of hydraulic and morphologic parameters using stream classification criteria (Rosgen 1994).

Though not specifically ecologically based, the objective of geomorphically based stream restoration is to restore natural geomorphic forms and processes. Restoration of geomorphic form, however, does not necessarily restore geomorphic process. Streams are complex geomorphic features (Schumm 1984), shaped and controlled by numerous internal and external processes and conditions. Like human beings, streams are singular or unique, even though all streams share many common characteristics (Schumm 1984). This combination of complexity and singularity means that restoring a stream to some particular form does not guarantee that riparian processes will be reestablished. Also, because a large flood following restoration could wipe out the project (Kondolf & Micheli 1995), designs often call for bank protection that will lock a stream in place. This necessary stabilization of the restored channel may reduce the geomorphic variability upon which the riparian system is dependent.

Direct Modification of the Riparian Ecosystem. Riparian ecosystems, particularly along larger rivers, represent vast land expanses that have been used and populated by humans. Anthropogenic disturbances that affect the riparian zone include those that can be eliminated and those that cannot. Situations where the disturbance can be eliminated may allow for a full restoration to natural conditions. Where the disturbance cannot be removed, limited enhancement from the existing situation may be all that is possible. In still other cases—for example, where the entire valley floor has been mined and mining is completed—reconstruction of the entire alluvial valley floor may be necessary. Unlike channelization or damming, many of these anthropogenic disturbances may have little direct effect on streamflow hydrology or channel morphology.

On land used for grazing, timber, and agriculture, removal of the stressor activity may allow recovery of the riparian ecosystem, if permanent, irreversible damage has not occurred. Eliminating the disturbance through a management policy may be all that is required. However, in many cases, eliminating exotic species and carrying out revegetation with native species are necessary (Anderson & Ohmart 1985; Carlson et al. 1992; Risser & Harris 1989). Eliminating grazing through fencing, along with some stream modifications to raise water tables, may be required for heavily grazed riparian areas (Platts & Rinne 1985; Connin 1991; Van Haveren & Jackson 1986).

Urban uses of riparian areas generally preclude their recovery, because the uses (houses, highways, etc.) may not easily be removed. Flows increase in urban streams due to greater runoff from developed lands, and stream channels are likely to be excavated, deepened, and widened for use as floodways that remove stormwater from urban areas. Toxic, nutrient-rich runoff may pollute stream waters. Restoration of streams to a natural-looking, meandering pattern and creation of riparian green belts may provide the best recovery potential (Keller 1976; Nunnally 1980; Ferguson 1991). At best, this could be termed landscape rehabilitation and not ecological restoration.

Mining actions that obliterate a valley floor with its riparian and aquatic ecosystems require the most intense restoration activities. Not only must the surficial elements of the stream and floodplain be reconstructed, but also a groundwater alluvial aquifer must be configured to support the riparian vegetation (Keller & Kondolf 1990). Mining laws and riparian rehabilitation efforts have been directed more towards meeting reclamation requirements than towards ecological restoration (Wiener 1980). Restoration approaches have generally been related to ensuring the reconstruction of the stream channel to a natural meandering pattern (Rechard & Schaefer 1984; Hasfurther 1985).

Watershed Disturbances. Human activities in a watershed that modify water and sediment production, including farming, road construction, and logging, may affect a riparian ecosystem and its restoration potential, because the riparian zone and its associated stream integrate watershed conditions (Lotspeich 1980; Frissell et al. 1986). Schumm (1977) considered an idealized fluvial system to consist of three zones: the watershed where water and sediment are produced, the river system where sediment transfer occurs, and a sediment sink where deposition occurs. Production of water and sediment in the watershed is dependent upon geology, climate, soils, vegetation, and land use (Lotspeich 1980). Anthropogenic activities in the watershed are off-site disturbances (from a riparian zone perspective) that modify water or sediment yield from the watershed and thereby modify water and sediment flux through a stream reach. Watershed changes can result in higher peak flows, lower or higher base flows, changes in runoff timing, or increased sediment production. These watershed changes may be manifested in the riparian zone by channel degradation, aggradation or widening, lowering of the alluvial groundwater table, and modifications to fluvial processes (Keller & Kondolf 1990; McGlothlin et al. 1988).

Because riparian ecosystems are dependent on their watersheds, larger scale watershed and river basin approaches to restoration may be necessary to solve riparian zone problems (McGlothlin et al. 1988; DeBano & Schmidt 1989, 1990). Managing grazing to allow vegetation and soil structure recovery is often an option in the

West where grazing is a major land use. In addition to watershed treatments, in-channel structures may be required to stabilize channels, reduce sediment, and extend the duration of streamflow (DeBano & Schmidt 1989). If the watershed cannot be restored, the stream channel and riparian zone must be rehabilitated to a state in equilibrium with the watershed's ongoing water-sediment production regime (Brookes 1987; Morris 1995).

Perspective on Future Directions: Approaches and Challenges

This review led us to four general conclusions about future needs in riparian restoration. We summarize these four issues in the discussion that follows.

Need for Interdisciplinary Approaches. A keystone paper published nearly four decades ago by Hack and Goodlett (1960) illustrated the utility of combining the disciplines of geomorphology and ecology. While many of the disparate disciplines involved in riparian restoration have rapidly advanced their science during the past 20 years, much of the effort has been conducted along disciplinary lines. The lack of interdisciplinary cooperation has resulted in a failure to adopt a unified conceptual framework for studying riparian zones (Malanson 1995). This disciplinary isolation must end before substantial progress in riparian restoration can be made. Interdisciplinary approaches have previously been proposed (Wesche 1985; Orsborn & Anderson 1986; DeBano & Heede 1987). Fortunately, progress in this direction is occurring, as illustrated by the interdisciplinary approach to watershed analysis and management advanced by state and federal governments (U.S. Forest Service 1994). Articles in this volume (Kershner 1997; Nehlsen 1997) are also evidence of the collaboration among various disciplines.

Need for a Unified Framework for Approaching Riparian Restorations. A consistent framework for planning and evaluating restoration studies is greatly needed. The fluvial system is complex, and conditions at specific locations are singular (Schumm 1984). A unified framework, similar in potential to the River Continuum Concept (Vannote et al. 1980) framework for stream ecosystems, would provide a means of comparing restoration efforts at diverse locations. This volume represents a first step in developing a framework that operates at the scale of the watershed.

A hydrogeomorphic framework is appropriate because hydrologic and geomorphic processes distinguish the riparian ecosystem from the upland ecosystem (Brinson et al. 1981; Gregory et al. 1991). Also, water and sediment fluxes and a flood-induced disturbance regime are critical aspects of riparian ecosystems. The beginnings of such a framework have been proposed by Kondolf and Micheli (1995), though their framework is more for restoration evaluation than for restoration planning. Jensen and Platts (1990), Kovalchik and Chitwood (1990), Gregory et al. (1991), and Carlson et al. (1992) all suggest that geomorphology be used as the foundation for understanding the riparian zone ecosystem and for its restoration. Several of the approaches to prioritizing sites for restoration presented in this volume (Harris & Olson 1997; O'Neill et al. 1997; Russell et al. 1997) use hydrogeomorphology as the basis for their methods. Streamflow hydrology has been a forgotten component in many classification systems. As Whiting and Stamm (1995) illustrated, the geomorphic form and ecological character of spring-dominated streams are significantly different from those of flashy, runoff-dominated streams. Thus, the framework must incorporate a description of streamflow variability and predictability, possibly similar to that proposed by Poff and Ward (1989) for understanding stream ecosystems.

To be most useful for restoration projects, a riparian classification system should not only describe existing conditions but also describe restoration potential. The capacity to identify future processes, rather than existing forms, is the next logical step toward developing the approaches presented in this volume.

Need for Understanding Processes. Probably the greatest challenge we foresee to making true progress in riparian ecosystem restoration lies in understanding the underlying physical and ecological processes of the riparian zone and the interactions and feedback among these processes (Gregory et al. 1991). Many of the restorations undertaken to date have used simple empirical relationships or undisturbed sites as templates to provide a basis for restoring stream and riparian form and, hopefully, functions.

Simple empirical relationships unfortunately tell us nothing about why a certain restoration design is the best to use. Geomorphic form simply is used as a surrogate for geomorphic process, since the understanding of geomorphic process is still rather limited. Typical empirical geomorphic relationships, however, show order-of-magnitude ranges with regression lines traversing clouds of data points. These relationships are of little use in answering questions about how disparate energy levels on the floodplains (Nanson & Croke 1992) of different streams differentiate the riparian plant community into patches. Neither can we realistically extrapolate these natural stream relationships to a completely disturbed (e.g., mined) system, where total valley floor reconstruction provides no basis for natural restoration. We believe that a restoration approach based upon a paradigm of re-establishing physical and ecological processes rather than forms must be devised so that such questions can be answered completely.

Progress is being made, however, in developing physically based understandings of riparian zone processes and functional relationships. Nanson and Croke (1992) have made an initial effort to relate floodplain form and sedimentation processes to streamflow energies. O'Neill et al. (1997) use the magnitude of stream power as one element in identifying stream reaches with the most restoration potential. The interrelationships between riparian systems and the hydrologic and geomorphic processes operating in the associated stream channel have been examined by Van Haveren and Jackson (1986). Auble et al. (1994) have used physically based concepts of river hydraulics to predict riparian plant distributions. Recruitment of *Populus deltoides*, var. *occidentalis Rydb.* (plains cottonwood tree) has been placed within a context of geomorphic and sedimentologic processes (Bradley & Smith 1985), with alteration of these physical processes being shown to affect cottonwood recruitment below major dams (Rood & Mahoney 1990). Hupp (1992) and Hupp and Simon (1991) provide a six-stage process model that defines natural channel evolution and revegetation processes of channelized rivers. Olson and Harris (1997) classify vegetation and develop restoration strategies using landform and substrate types as indicators of flooding intensity and stability.

These studies and others provide the direction for sound physically and ecologically based conceptual models of riparian ecosystem processes. However, many other riparian ecosystem processes (e.g., decomposition, nutrient uptake during flooding, and denitrification) have rarely been considered from a restoration perspective. Full comprehension of all ecosystem processes is necessary for a holistic understanding of the ecosystem. Learning from past experience—in which failures may prove as valuable as successes in expanding the state of restoration science (Kondolf 1995)—and adopting a process-based approach to restoration should guide the future direction of riparian zone restoration.

Need for Considering the Causes of Degraded Conditions. In addition to understanding the hydrogeomorphic framework and recognizing the potential physical and biological processes at a restoration site, we must thoroughly understand the anthropogenic disturbances that created the degraded condition. Three specific questions should be addressed, for the answers will limit and guide restoration activities.

Is the Disturbance Local to the Riparian Area or Does It Originate Outside in the Adjacent Upland or Watershed? Anthropogenic disturbances local to the riparian area are often more easily fixed than those originating from outside the area, as off-site land and water control issues may be unresolvable. Watershed-based approaches for locating riparian restoration sites are proposed by most of the papers in this volume (Nehlsen; Kershner; Hawkins et al.; Russell et al.; Harris & Olson; Olson & Harris), which is a recognition of the explicit linkages that exist among watershed, floodplain, and stream (Frissell et al. 1986; DeBano & Schmidt 1990). Many methods for improving poor stream and riparian conditions, including soil conditioning, revegetation, bank stabilization, and meander re-establishment, have been presented in the literature (e.g., Anderson & Ohmart 1985; Henderson 1986; Brookes 1987; Carlson et al. 1992; Rosgen 1994; Newbury 1995). Understanding existing and potential watershed disturbance effects upon watershed water and sediment production is essential to selecting appropriate restoration methods.

Is the Disturbance Ongoing, and if so, Can It Be Eliminated? Where an anthropogenic disturbance will continue, restoration to a predisturbance condition is not possible. The best on-site situation that can be achieved is a new natural condition in equilibrium with the disturbance (Brookes 1987; Morris 1995). Conversely, a site selected upstream from a significant ongoing disturbance is likely to have better restoration potential (Hawkins et al. 1997; Russell et al. 1997).

Will Recovery Occur Naturally if the Disturbance Is Removed? In some situations, removal of an anthropogenic disturbance, such as light livestock grazing, may allow nearly complete recovery with no intervention. Recovery may be faster with intervention, but there must be a balance between desired recovery speed and restoration budget. At the other extreme, some heavily disturbed systems may not recover without massive human intervention, suggesting a low priority for restoration. Nehlsen (1997) suggests an approach of first removing human-caused perturbations and then allowing time for natural recovery. If natural recovery does not occur quickly enough, then restoration activities can be implemented.

A restoration project that does not address these three questions will in all likelihood fail, at least partially. However, proper site selection as suggested by the approaches presented in the papers of this volume will increase the opportunity for successful recovery.

Concluding Thoughts

Although still in its formative stages, restoration science for riparian ecosystems is growing rapidly. Riparian restoration requires the *a priori* specification of a set of physical and ecological conditions to be established at a restoration site. These conditions must be naturally sustainable given a set of water, sediment, and energy fluxes. If the conditions cannot be naturally sustained, the restoration will fail to meet the original goals. Because many of the relationships among riparian plants, geomorphic forms, and hydrogeomorphic processes are incompletely understood (Hupp & Osterkamp 1996), and because extrapolations from one location to another nearby site may be fraught with problems (Schumm 1984), future riparian restoration failures are likely. An improved understanding of riparian zone hydrogeomorphic processes, of which the papers in this volume are examples, will provide the basis for better restorations in the future.

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