An Ecological Perspective of Riparian and Stream Restoration in the Western united States

By J. Boone Kauffman, Robert L. Beschta, Nick Otting, and Danna Lytjen

ABSTRACT

There is an unprecedented need to preserve and restore aquatic and riparian biological diversity before extinction eliminates the opportunity. *Ecological restoration* is the reestablishment of processes, functions, and related biological, chemical, and physical linkages between the aquatic and associated riparian ecosystems; it is the repairing of damage caused by human activities. The first and most critical step in ecological restoration is *passive restoration,* the cessation of those anthropogenic activities that are causing degradation or preventing recovery. Given the capacity of riparian ecosystems to naturally recover, often this is all that is needed to achieve successful restoration. Prior to implementation of active restoration approaches (e.g., instream structures, channel and streambank reconfiguration, and planting programs), a period of time sufficient for natural recovery is recommended. Unfortunately, structural additions and active manipulations are frequently undertaken without halting degrading land use activities or allowing sufficient time for natural recovery to occur. These scenarios represent a misinterpretation of ecosystem needs, can exacerbate the degree of degradation, and can cause further difficulties in restoration. Restoration should be undertaken at the watershed or landscape scale. Riparian and stream ecosystems have largely been degraded by ecosystemwide, off-channel activities and, therefore, cannot be restored by focusing solely on manipulations within the channel. While ecological restoration comes at a high cost, it also is an investment in the natural capital of riparian and aquatic systems and the environmental wealth of the nation.

A fence-line contrast of a five-year-old exclosure (without livestock grazing) and an area grazed season-long on a tributary of the Deschutes River, Oregon. The cessation of those activities that are causing degradation or preventing recovery is the most important step in ecological restoration. Given the natural resilience capacity of riparian ecosystems, passive restoration such as halting excessive livestock grazing is all that is needed to restore degraded riparian ecosystems.

Traditionally, the use and management of rivers, riparian zones, and wetlands have focused on activities that led to increases in the social well-being or material wealth of a society. These included such endeavors as transportation, hydroelectric power generation, flood control, and the use of water for agricultural, industrial, and municipal uses (National Research Council 1992).

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As a result of these practices, as well as activities such as channelization, road construction, timber harvesting, livestock grazing, mining, and water diversion, numerous riparian zones in the western United States have been extensively altered since Euro-American settlement (National Research Council 1995, 1996). The resulting decreases in diversity, functions, and productivity of riparian and aquatic ecosystems limit their future integrity, value, and use. This is an important societal concern since riparian zones are among the nation's most highly valued, yet threatened natural ecosystems (Johnson and McCormick 1979; National Research Council 1995).

Riparian and aquatic ecosystems are currently being altered, impacted, or destroyed at a greater rate than any time in history (National Research Council 1992).

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An estimated 70%-90% of all natural riparian areas in the United States have been extensively altered (Hirsch and Segelquist 1978); approximately 47.3 million ha (117 million acres) or 53% of all U.S. wetlands have been lost since the 1780s (Dahl 1990). Some widespread land uses that occur in both uplands and riparian systems exert their greatest impacts on streamside areas. For example, in the 11 western states, livestock grazing is permitted on 91% of all public lands. On the 64 million ha (158 million acres) of Bureau of Land Management-administered lands, 58% is classified in fair to poor condition (i.e., the lands have been moderately to severely desertified) as a result of long-term grazing (U.S. General Accounting Office 1988). Historical grazing impacts to riparian systems have been even more severe. On these public lands, 25,700 km (16,000 miles) of sportfishing streams have declined in quality as a result of land use practices (Armour et al. 1991).

Degradation of riparian zones and streams diminishes their capacity to provide critical ecosystem functions, including the cycling and chemical transformation of nutrients, purification of water, attenuation of floods, maintenance of stream flows and stream temperatures, recharging of groundwater, and establishment and maintenance of habitats for fish and wildlife. The most important factor contributing to the decline of aquatic biodiversity is the loss or degradation of habitats (i.e., habitat alteration, introduced species, and water pollution; Miller et al. 1989). Almost 40% of the perennial streams in the United States are affected by reduced flows, and 41% are influenced by siltation, bank erosion, and channelization (National Research Council 1992). More than half of the nation's rivers have fish communities harmed by turbidity, high temperatures, toxins, and low levels of dissolved oxygen (Council on Environmental Quality 1989). Almost 85% of historical Pacific Northwest anadromous salmon stocks are either extinct, endangered, threatened, or of special concern (National Research Council 1996). The current threat to aquatic biodiversity in North America is greater than the threat to terrestrial diversity (Naiman et al. 1995). While 11%-15% of the terrestrial vertebrates are considered rare or nearly extinct, 34% of the fishes, 65% of the crayfishes, and 75% of the bivalve mussels fall into these categories (Naiman et al 1995). To date, not a single aquatic species has been delisted through Endangered Species Act procedures because of implementation of a successful recovery plan; in fact, the majority of the listed species do not have a formal recovery plan (Williams et al. 1989). An unprecedented need exists for ecological restoration of riparian ecosystems and their closely associated aquatic ecosystems.

What Is Ecological Restoration?

Ecological restoration in riparian ecosystems is defined as the reestablishment of predisturbance riparian functions and related chemical, biological, and physical processes (National Research Council 1992). *Restoration* is the process of repairing damage caused by humans to the diversity and dynamics of indigenous ecosystems (Jackson et al. 1995). While ecological restoration attempts to return riparian zones as closely as possible to predisturbance functions and processes, scientists must recognize that ecosystems are in a constant state of flux due to ever-changing environmental conditions. These changes, sometimes coupled with irreversible human impacts (e.g., soil loss, biotic invasions, air pollution), may preclude our capability to precisely re-create ecosystem structure and functions that previously existed. Thus, the goal of restoration projects is to ensure that the dynamics of natural ecosystem processes are again operating efficiently so that both ecosystem structure and function can be recovered (National Research Council 1992).

Riparian areas are three-dimensional zones of biological, physical, and chemical interactions between terrestrial and aquatic ecosystems (Gregory et al. 1991). Because of landscape-level interactions between terrestrial and aquatic systems, ecological restoration of riparian zones requires a holistic approach whereby activities and conditions across an entire watershed should be considered. Problems affecting riparian and aquatic resources are unlikely to be solved by ignoring deleterious land management practices, either historical or current, that occur at landscape or watershed scales.

While scientists strongly recognize the need to restore or conserve native fish throughout the Pacific Northwest and other nearby regions, less appreciation exists for how local geomorphic settings and natural hydrologic disturbance regimes interact with native riparian plant communities to create sustainable habitats (Figure 1). Restoration of degraded riparian zones and their subsequent conservation after recovery requires knowledge of how these ecosystems function as well as the attributes responsible for their composition, structure, and productivity. The character and value of riparian zones arise as a result of an infinite number of complex interactions among three fundamental ecosystem features: (1) soils/geomorphology; (2) hydrology; and (3) biota (Figure 1). The soils/geomorphology features include streambank and floodplain form and development, channel gradient, geologic substrates influencing soil and channel composition, and subsoil features of the floodplain (e.g., gravel lenses important for hyporheic or subsurface flows). Hydrological features include the frequency, magnitude, and temporal distribution of stream flow (including peak and low flows), sediment availability and transport, subsurface hydrology, and water quality. Biotic features include vegetation, vertebrates, invertebrates, and microorganisms. In addition to live plants, the vegetation component also includes dead materials (necromass) such as snags, fallen logs, and fine organic debris (litter). Anthropogenic activities that either alter these components or sever the linkages between them will disrupt ecosystem dynamics, including species composition, productivity, structure, and function.

Among the most important ecosystem linkages are those interactions among vegetation, hydrology, and substrates as they influence geomorphic features such as channel morphology and channel dynamics (Figure 1). For example, naturally occurring pool habitats typically form as a result of interactions of hydrologic disturbance regimes, substrates, and streamside vegetation. If hydrologic patterns, sediment availability, or streamside vegetation are altered by land use activities, then channel morphology will subsequently adjust to these new conditions. This is often expressed by a simplification in stream structure (e.g., loss of pools, decreased channel sinuosity, and loss of channel diversity).

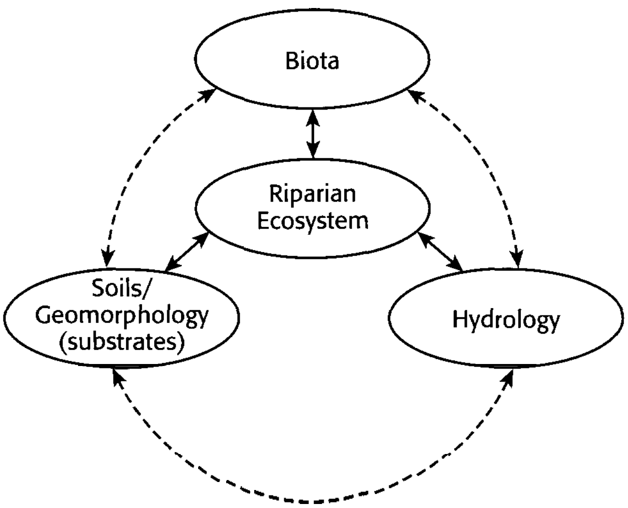

Figure 1 illustrates the linkages of the biotic, hydrologic, and geomorphic components combined to shape the unique structure and function of riparian and stream ecosystems. Each arrow represents an infinite number of biological and physical processes and interrelationships among these ecosystem features. Because of these inextricable linkages, human or natural actions that alter any one component or process will have feed-forward influences that can affect all other components of the ecosystem.

Another important interaction represented in Figure 1 is the influence of substrate characteristics and hydrology on plant community composition. For example, many riparian-obligate trees and shrubs have specific micro-site requirements for establishment. Successful natural establishment of cottonwood trees (*Populus* spp.) and willows (*Salix* spp.) commonly occurs on point bars of newly deposited, coarsely textured, well-aerated substrates within the 2- to lo-year floodplain (McBride and Strahan 1984; Bradley and Smith 1986); high flows are needed to create these conditions. Seed dispersal and germination are timed to coincide with late-spring flows when water tables are high, and fresh alluvium has been deposited (Noble 1979). Successful establishment also may be limited to areas where the rate and extent of water table decline does not exceed the biological capacity of root growth (Mahoney and Rood 1992). At the lower limits of the floodplain, establishment is often not possible because high water in subsequent years destroys the young plants (Bradley and Smith 1986).

Saturated, finely textured soils associated with low-gradient riparian zones are often sites of anaerobic conditions; such sites are typically unsuitable for the establishment of cottonwoods or willows. Under these hydrologic and geomorphic conditions, the natural plant communities are dominated by sedges (*Carex* spp.), rushes (*Juncus* spp.), or hydrophytic grasses. At the opposite extreme, where coarse materials (cobbles and boulders) occur in elevated and excessively drained situations, riparian-obligate vegetation will not establish. These conditions rarely occur naturally in western riparian ecosystems. However, they may be found after extreme human perturbations (e.g., dredge mining, channelization, or other in-channel modifications) deposit spoils on streambanks and floodplains.

Ecological restoration begins with identification of those land use practices that are damaging ecosystems or preventing recovery, followed by implementation of land management strategies that allow for natural recovery to occur (National Research Council 1992, 1996; Jackson et al. 1995). Thus, ecological restoration aims to ensure the occurrence of (1) those physical and biotic processes facilitating persistence of species through natural recruitment and survival; (2) functioning food webs and systemwide nutrient conservation via relationships among plants, animals, and detritivores; and (3) the integrity of watersheds through linkages with the hydrologic, geomorphic, and climatic disturbance regimes that shape plant and animal communities (Jackson et al. 1995).

What Isn't Ecological Restoration?

Ecological restoration results in the reestablishment of linkages between organisms and their environment. Because an entire suite of organisms, physical features, and processes comprise an ecosystem, a species-only or single-process approach to restoration will likely fail (Beschta et al.

Photos by J. B. Kauffman

The influence of restoring streamflow and halting grazing on Rush Creek, California, (1992– 1996) is illustrated above. The small willow in the foreground in 1992 (left) is the same willow to the left of the third author in 1996. In 1992, a high density (50 m^{-2}) of willow seedlings, was established on the gravel bar the first year without livestock. By 1996, a dense willow community had formed, with many willows becoming more than 2 m in height.

1994; Jackson et al. 1995). For example, the reintroduction of an extirpated fish species or the installation of log weirs and large boulders into a degraded stream reach does not constitute restoration. While attempts to revive a single species are likely to target only a few of its more obvious habitat requirements, less-apparent needs and important processes and functions are often ignored. In the case of declining anadromous salmonids, a technological perspective has prevailed (Bottom 1997); first fish hatcheries, then fish ladders, and finally in-stream manipulations were looked on as solutions. However, increasingly apparent is that there is a remarkable complexity of environmental phenomena that affect salmon viability, and the cumulative losses of various biotic and physical components are what must be addressed (National Research Council 1996). By shifting the focus to the integrity of ecological processes and functions, we are more likely to successfully attain the restoration both of habitats and species of interest.

Ecological restoration also should be distinguished from architectural and mechanical approaches to ecosystem management. Such "restoration" methodologies often call for the systematic reconstruction of a stream according to specific human perspectives of what the stream "should look like." More often than not, this will not achieve the goal of ecological restoration or species recovery. Merely re-creating a form without the function or the function in an artificial configuration does not constitute restoration (National Research Council 1992). A long-term perspective regarding ecosystem sustainability is not inherent with these approaches. For example, the placement of artificial structures (boulders, rock gabions) does not replace many of the multiple functions of large, woody debris, nor does it ensure or promote the future recruitment of woody debris into the stream system. Such structures are commonly engineered and constructed with the false assumption that they and the stream channel are static. High flows can be destructive when rigid structures are placed in degraded alluvial channels (Beschta et al. 1991; Gregory and Bisson 1997). The underlying failure of this approach rests in a lack of recognition regarding the natural dynamics of high-flow disturbances, bedload transport, local scour and fill, lateral channel movements, and particularly the interactions of streamside vegetation with fluvial disturbance regimes.

Fish hatcheries, fish ladders, and barging salmon downstream in dammed rivers are artificial means of maintaining anadromous fish in systems (functions with no natural form). These approaches seldom address fundamental problems associated with restoring the habitats of natural fish runs. Such activities could be construed to be mitigation or aquaculture but not restoration since they do nothing to restore habitat or reverse barriers to migration.

Preservation

Preservation is the maintenance of intact ecosystems; it is distinct from ecological restoration, which only addresses degraded ecosystems. Ecosystems that exist in a desired natural state warrant preservation (National Research Council 1992, 1996). The protection and preservation of intact ecosystems are of great importance, both environmentally and economically. Restoring the natural structure and function of riparian and stream ecosystems requires an understanding of the complex processes and linkages between the biotic and physical components of intact systems. Intact ecosystems are necessary as reference reaches from which to compare the efficacy of restoration programs (Case 1995; Beschta 1997). Furthermore, they are sources of natural genetic material for the reestablishment or reintroduction of the native biota to nearby areas in need of restoration.

Preservation is a management strategy that entails more than simply preventing human-induced alterations. For example, management actions may be necessary to maintain natural functions and characteristics (e.g., prescribed fire, management of exotic species invasions, and large herbivore management). Measures to protect intact ecosystems (preservation) are important because they are often easier to implement, have greater rates of success, and are less expensive than restoration. Preserving intact ecosystems also may be less expensive than restoring them, just as preventative medicine is nearly always less expensive than corrective medicine (National Research Council 1992; Cairns 1993).

Various other land management approaches seek to alter and improve riparian conditions or specific habitat features, yet they may not represent ecological restoration. Activities often confused with ecological restoration include creation, rehabilitation, reclamation, mitigation, replacement, and enhancement. These activities typically emphasize altering ecosystem components for a particular human purpose (National Research Council 1992, 1996).

Crea tion

Creation is defined as establishing a new ecosystem that previously did not exist on a particular site. For example, developing a sustainable wetland in an area formerly occupied by upland plant communities would represent creation. Creation also includes attempts to create specific riparian features that previously did not exist on the treated site. Examples include the planting of willows or alders *(Alnus* spp.) on riparian wetland sites naturally occupied by sedges or rushes, placement of boulders in streams with floodplains comprised of fine sediment, and construction of secondary channels where none existed previously (Quammen 1986) .

Reclamation

Reclamation is traditionally defined as the process of adapting wild or natural resources to serve a utilitarian human purpose (National Research Council 1992). Historically, this often included the conversion of riparian or wetland ecosystems to agricultural, industrial, or urban uses. More recently, however, reclamation has been defined as the process resulting in a stable, self-sustaining ecosystem that may or may not include some exotic species. Reclaimed sites may have similar, although not identical, structure and function of the original land (Jackson et al. 1995).

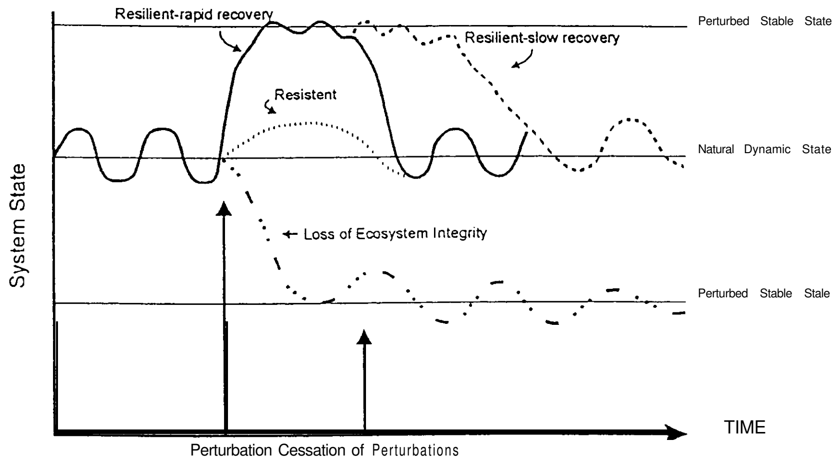

Figure 2 represents the conceptual responses of individual riparian plant communities to human perturbations and response pathways after cessation of perturbations. Resistant plant communities exhibit few deviations from natural equilibria when exposed to a perturbation. In contrast, nonresistant communities shift to a perturbed state unlike that of the natural dynamic state (i.e, changes in composition, structure, or productivity). After activities that caused ecosystem degradation (perturbations) stop, resilient communities will recover to natural system states. Nonresilient communities are those lacking potential for natural recovery and are characterized as having lost ecosystem integrity. In the absence of active restoration activities, they may remain indefinitely in an altered ecosystem state.

Rehabilitation

Rehabilitation implies making the land useful again after natural or anthropogenic disturbances. Restoration to predisturbance conditions and functions is not implied in the definition of *rehabilitation.* The creation of a crested wheatgrass *(Agropyron cristatum)* stand where sagebrush steppe *(Artemisia tridentata* once existed or the planting of exotic grass species after a forest fire could be construed as rehabilitation but is not ecological restoration.

Xeplacemen t

Replacement is the substitution of a native species or ecosystem feature with an exotic species or foreign object; often, it is considered another form of rehabilitation. Examples of replacement would include the planting of nonnative trees or the placement of boulders, gabions, or weirs to substitute for natural features. The introduction of brook trout *(Salvelinus fontinalis)* or smallmouth bass *(Micropteris dolomieui)* in streams historically occupied by native salmonids is an example of ecological replacement.

Mitigation

Mitigation is an attempt to alleviate any or all of the detrimental effects or environmental damage that arise from anthropogenic actions. The construction of fish hatcheries or the modification of headwater fish habitats to compensate for losses caused by dams is a mitigation approach. Wetland creation is often suggested as mitigation for the destruction of natural wetlands from construction, fill, or other human activities. However, these constructed wetlands seldom display the structural or functional attributes of the native wetlands they replaced (Quammen 1986; M. Kentula, U.S. Environmental Protection Agency, personal communication).

Enhancement

Enhancement is any improvement of a structural or functional attribute for a species or habitat. However, when enhancement activities are focused only on a single species or specific component of an ecosystem, they may create conditions outside the context of a natural riparian and stream system. For example, in-stream structures (e.g., rock jetties, gabions, pool excavations) are often used with the objective of fish habitat enhancement. However, these structures can severelv alter streambank structure, sediment transport dynamics, and hydrologic connectivity with riparian vegetation, resulting in disruptions or losses of riparian-stream linkages. When in-stream spoils, rocks, or boulders are piled on a streambank, conditions may no longer be suitable for natural establishment of riparian vegetation nor for adjustments in channel morphology to natural variations in sediment transport and stream flow. Such physical alterations may further limit the future recruitment potential of large, woody debris as well as degrade riparian wildlife habitat. The ecological costs and benefits to physical processes, biological diversity, and ecosystem functions should be considered before such actions are initiated.

Resistance and Resilience

In undertaking restoration, it is important to understand the response of riparian ecosystems to anthropogenic perturbations (resistance) as well as the capacity to recover after cessation or removal of the problem-causing activities (resilience). Resistance is the capacity of an ecosystem to maintain natural function and structure after a natural disturbance or an introduction of an anthropogenic perturbation. For example, some riparian meadow plants will maintain productivity with moderate levels of livestock grazing because of their adaptive capacities or tolerance to herbivory. These would be considered resistant *communities.* In contrast, even low levels of herbivory can retard community development on gravel bars dominated by young willow or cottonwoods (Case and Kauffman, in press; Green and Kauffman 1995); these are *nonresistant communities.*

Resilience is the capacity of species or ecosystems to recover after a natural disturbance or following the cessation of an anthropogenic perturbation. Because riparian species evolved in areas with frequent fluvial disturbances, they represent classic examples of a resilient biota. Not only do many riparian plants depend on natural disturbances for establishment, but rates of recovery or establishment following disturbances can be remarkably high (Busse 1989; Gecy and Wilson 1990; Case 1995). Paradoxically, while riparian ecosystems are often resilient to natural disturbance regimes, many rapidly degrade with the curtailment of these disturbances. For example, water impoundment and diversion projects have resulted in dramatic losses in riparian floodplain forests throughout North America (Bradley and Smith 1986; Rood and Mahoney 1990; Howe and Knopf 1991).

The conceptual pathways of riparian community response to the initiation and cessation of anthropogenic perturbations are illustrated in Figure 2. A severe anthropogenic perturbation (e.g., overgrazing, clear-cutting, channelization, dams, diversions) may sufficiently alter a riparian ecosystem such that it will attain a dynamic equilibrium different than what would occur under natural conditions. A *resistant ecosystem* is one that displays few changes in composition or structure following the initiation of a perturbation. In contrast, nonresistant riparian zones or communities will change to a new system state or equilibrium typified by a different composition (e.g., dominance by exotics), different structure (e.g., losses of the woody component), altered productivity (e.g., shifts in above- and below-ground biomass), or a change in ecosystem functions (e.g., influences on water quality).

After cessation of perturbations, resilient riparian ecosystems usually show signs of recovery through measurable changes in composition, structure, or function (Figure 2). In these situations, cessation of those human perturbations that harm the riparian ecosystem may be all that is necessary to achieve restoration. Because some ecosystems recover more quickly than others, it is important to monitor changes before implementing other, often more costly, measures. Failure to wait minimally may result in wasting limited funds; at worst, it may exacerbate the extent of degradation.

When losses in ecosystem structure, composition, or function reach a sufficient magnitude, the simple cessation of perturbations may not be sufficient for ecosystem recovery (Figure 2). Factors that may diminish resilience and, hence, prevent recovery include species extinctions, introductions of exotics, excessive soil erosion, pollution, and severe changes in geomorphology or hydrology. In these situations, the ecosystem may remain degraded indefinitely even after the cessation of activities that caused degradation. In this scenario a concerted and active effort will be needed to accomplish restoration.

Rather than referring to a handbook, land managers should obtain the "blueprints" for the ultimate outcomes of planned restoration activities from intact streams.

Conceptual Approaches to Restoration

The basic goal of riparian restoration is to facilitate a self-sustaining occurrence of natural processes and linkages among the terrestrial, riparian, and aquatic ecosystems. An important initial component of any restoration plan should be an evaluation of the ecological status of existing riparian and aquatic systems. Ideally, this assessment should be conducted at the watershed scale, while still being sufficiently detailed to depict specific reaches or channel units where particular restoration activities might ultimately occur. The objectives of the initial resource analysis should be to identify (1) those reaches that are relatively intact (few anthropogenic impacts evident) and worthy of protection or preservation management strategies; (2) those reaches where restoration% feasible with changes in current land use activities or without large expenditures of money; (3) those areas that could be restored-but only at high costs and with a high probability of failure, and (4) those reaches that are in a condition where restoration is not technically feasible due to extreme conditions of alteration, degradation, or sociopolitical limitations.

When planning for ecosystem restoration, it may be useful from a strategic perspective to partition riparian zones into those capable of rapid recovery, those with a slow rate of natural recovery, and those with little or no resilience capacity (i.e., loss of ecosystem integrity, Figure 2). The greatest efforts should be initially focused on the former because of a greater potential for successful restoration with lowered risk or expenditures. Only after areas with a high-resilience capacity are improving or have been restored should restoration efforts focus on areas that have generally lost the capability of natural recovery, even after the cessation of human perturbations. However, special situations may exist in which degraded habitats of species near extinction can only be restored at high risk and cost; such areas assume a high priority for improvement.

Where possible, managers should emphasize preservation because preservation of intact ecosystems is typically less expensive than restoring degraded systems (Cairns 1993). Intact ecosystems are not only valuable sources of biological diversity, but they also provide important reference sites that land managers may seek to emulate in their restoration activities. Rather than referring to a handbook, land managers should obtain the "blueprints" for the ultimate outcomes of planned restoration activities in adjacent sites from intact streams. Because the failure rate of restoring degraded ecosystems is far greater than that of simply protecting fully functional sites, protecting and preserving intact ecosystems should represent the first priority of any watershed-scale restoration plan.

At the other extreme, many areas exist where ecological restoration in the strictest sense is neither economically, socially, nor technologically feasible (e.g., metropolitan reaches, dredged mine sites, etc.). If restoration practices are pursued in these situations, they may be costly. However, stream enhancement activities should not be ruled out in these scenarios, particularly if such activities would diminish harm to downstream or upstream riparian and aquatic ecosystems.

Reviews of instream habitat management projects throughout the western United States clearly indicate that passive restoration has been the critical first step in successful riparian restoration programs.

The domain of riparian and stream restoration lies between these two extremes (Figure 2). A successful riparian restoration program will result in the perpetuation of processes that determine ecosystem structure, function, and evolutionary trajectory. However, this operating principle is stated with the recognition that the intact wildlands of today and the future will exist in a fragmented landscape and will require specific preservation management activities such as prescribed fires, suppression of arson fires, control of biotic invasions, and maintenance of natural hydrologic disturbance regimes.

After identifying those degraded sites where restoration is deemed feasible, scientists must determine the causes of degradation and the activities preventing recovery (Beschta 1997). Also important is the identification of biotic components of the ecosystem that have been extirpated and the presence of biotic invaders that may prevent recovery. In addition to biotic considerations, scientists must determine the degree to which the hydrologic and geomorphic features of the ecosystem have been (or are being) altered. This includes determining the influences of past management activities on channel morphology, channel incision, hyporheic flows, water table dynamics, and water quality (i.e., the linkages between the terrestrial and aquatic system). From this initial analysis, not only can the extent and causes of ecosystem degradation be addressed, but potential restoration options may become evident. Obviously, even at this stage, restoration is a multidisciplinary effort.

The desired endpoints of restoration efforts are naturally dynamic and self-sustaining ecosystems (Figure 2). Given the fluctuating nature of environmental factors inherent to all natural systems, restoration managers should emphasize ecosystem processes and function rather than some preconceived landscape form. Fisheries professionals should recognize that because of the likely permanence of many exotic species, extinctions of native species, long-term changes in soil productivity due to erosion, and other severe environmental perturbations, complete recovery may not always be possible. In such cases, goals of restoration are to return a riparian system to a "potential natural community," whereby the ecosystem is naturally functioning in a manner as closely as possible to that in which it evolved.

Passive Restoration

Once professionals have decided where to implement restoration activities, the first and most critical step is to halt activities causing degradation or preventing recovery, an approach referred to as *passive* or *natural restoration* (Kauffman et al. 1993; Kauffman et al. 1995). Many riparian zones are capable of rapid recovery after human perturbations stop because the biota has evolved adaptations to survive and even reproduce despite frequent natural disturbance events characteristic of riverine systems (Barnes 1983; Wilson 1970; Gecy and Wilson 1990).

In western riparian zones the two most common examples of successful passive ecological restoration are the rewatering of streams after years of withdrawal for agricultural or municipal purposes and the cessation of livestock grazing in riparian areas. Stream flow diversion, combined with heavy livestock grazing, can result in severe degradation of riparian and stream ecosystems. With the return of perennial instream flows and the halt of livestock grazing, the recovery of riparian vegetation can be dramatic. For example, in the Mono basin of California, 24% of the area of riparian vegetation lost during a 50-yr period of water diversion (1940-1989) had reestablished after only 4 years following rewatering (Jones and Stokes Associates, Inc., and Trihey Associates, personal communication). Along these recovering streams, willow and cottonwood seedling densities were often >50 m^{-2} with annual growth rates of 0.6 to 1.5 m high (B. Kauffman and R. Beschta, Oregon State University, personal communication). Now, vegetation establishment is beginning to influence channel diversity through the creation of narrower channels, bank undercuts, and pools. In contrast, while several million dollars has been spent on engineering manipulations in and around stream channels, the influence of those manipulations on trout densities was insignificant and actually hurt the natural restoration process of the riparian and stream ecosystem (Beschta et al. 1994; Inter-Fluve 1995; W. S. Platts, Don Chapman and Consultants, personal communications).

Livestock grazing has been perhaps the most prevalent cause of ecological degradation for many western riparian and stream ecosystems (Kauffman and Krueger 1984; Kauffman 1988; Fleischner 1994). After extensive field reviews of fish habitat improvement projects in eastern Oregon, Beschta et al. (1991) and Kauffman et al. (1993) concluded that the cessation of livestock grazing in riparian zones of eastern Oregon was the single most ecologically effective approach to restoring salmonid habitats.

While many reviews of grazing effects on riparian vegetation have been general in nature (e.g., Platts 1991; Elmore and Kauffman 1994), recent research is providing improved insights into the effects of grazing on woody riparian species. This research is important because willows, cottonwoods, and alders are significant features of terrestrial wildlife habitat, stream channel morphology, and aquatic habitat. In central Oregon, Busse (1989) found a lack of willow and cottonwood reproduction in grazed

misinterpreting ecosystem needs is common with many instream rehabilitation and enhancement programs

riparian zones of the Crooked River National Grassland. After constructing corridor fencing, she recorded a widespread and rapid rate of willow and cottonwood establishment. In northeast Oregon, similar rates of woody species recovery after cattle grazing stopped have been quantified (Green and Kauffman 1995; Case and Kauffman, in press). Three years after cattle grazing stopped on Meadow Creek (a tributary of the Grande Ronde River), Case and Kauffman (in press) reported that the average crown volume of willows increased nearly 300%. Average crown volume of black cottonwood and alder increased 800% and 200%, respectively. Comparing 10 years of no grazing with light to moderate late-season grazing use in northeast Oregon, Green and Kauffman (1995) reported significant increases in both the density and structural complexity of willows and cottonwoods in ungrazed exclosures. Although positive trends in willow density and height also occurred in the lightly to moderately grazed areas (three weeks annually late in the season), recovery rates were significantly less than those of the ungrazed areas.

Reviews of instream habitat management projects throughout the western United States clearly indicate that passive restoration has been the critical first step in successful riparian restoration programs (Beschta et al. 1991; Kauffman et al. 1993; Beschta et al. 1994). In many cases, this was all that was needed to initiate restoration of riparian ecosystems. Because of the high costs and potential for failure with active restoration and manipulation, we recommended that project managers monitor and observe the natural recovery process for an appropriate period of time (e.g., 10 years) after implementing passive restoration. Then, if managers ascertain that natural recovery is limited or not occurring, implementation of active restoration projects might begin.

Active Restoration

After implementing passive restoration, a site still may remain in an ecological state that is unlike what would occur naturally (Figures 2 and 3). These situations can occur when an ecosystem is sufficiently degraded such that the inherent capacity to recover has been lost. To achieve ecological restoration in such situations, active manipulations will be necessary.

Many factors may prevent a return to a natural dynamic system when using only passive restoration-species extinctions [particularly keystone species such as cottonwood or beaver (*Castor canadensis*)] exotic predators [smallmouth bass or bullfrogs (*Rana catesbeiana*)], exotic competitors [carp (*Cyprinus carpio*), reed canary grass (*Phalaris arundinacea*), or knapweeds (*Centaurea* spp.)], loss of hydrologic function and alteration of hydrologic disturbance regimes (e.g., diversions, regulated flows by dams, disruptions of groundwater flow patterns), and alteration of geomorphic features (e.g., channel incision, soil erosion compaction). While some of these barriers to recovery might be easily ameliorated, others can be sufficiently severe in their magnitude and persistence that restoration may not be technologically feasible.

Biotic manipulations representing active ecological restoration include the reintroduction of beaver or plant species that have been extirpated from the area. Reintroductions are most successful when a feasibility analysis has confirmed that suitable habitat is present for the organism to be reintroduced. In the case of beaver, adequate habitat conditions include sufficient availability of forage and suitable structure of riparian plant communities. If introduced into degraded or recovering ecosystems before woody species have sufficiently reestablished, beaver can actually limit ecological recovery (Kauffman et al. 1982; Case 1995). Alternatively, when reintroduced in suitable riparian habitat conditions, the beaver can dramatically accelerate the restoration process through its influence on the hydrology, wetland extent, species composition, and quality of salmonid habitats (Naiman et al. 1988; Lowry 1993).

Vegetation plantings are a commonly proposed restoration technique. However, after passive restoration is implemented, the natural capacity for rapid reinvasion of woody species on suitable sites often makes artificial plantings unnecessary (Busse 1989; Schulz and Leineger 1990; Case and Kauffman, in press). Where shrubs and other woody species have been eliminated and the potential for natural reinvasion no longer exists, active revegetation will be required. For example, where high-flow regimes have been significantly altered (e.g., below a

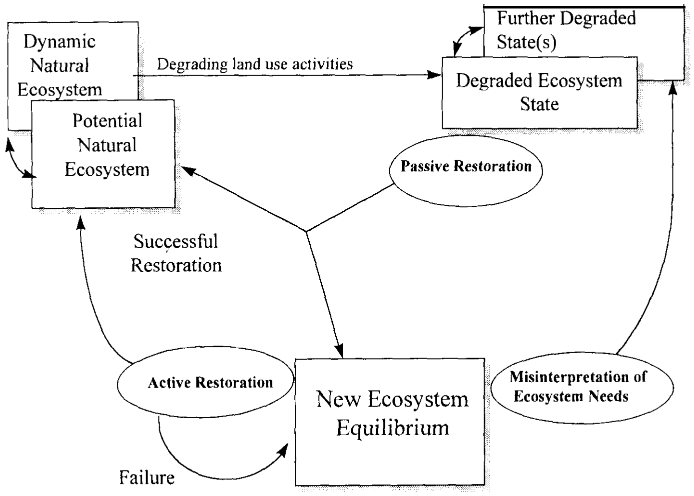

Figure 3 explores the conceptual pathways or ecosystem response to ecological restoration of western North American riparian and stream ecosystems.

major dam), the natural regeneration of riparian-obligate trees and other woody species may be severely limited (Bradley and Smith 1986; Rood and Mahoney 1990). Without a recovery of high-flow regimes, artificial revegetation will likely be necessary to perpetuate forests within the historic floodplains. Gallery forests can be naturally perpetuated only if flow management allows high-water events to create conditions for regeneration.

By definition, ecological restoration of riparian vegetation entails the planting of only native species. The use of exotic plant species to "improve" riparian habitats associated with native fisheries is tantamount to introducing brook trout (Salvelinus fontinalis) or some other exotic fish as a substitute for extirpated native bull trout *(Salvelinus* confluentus) populations. In addition, revegetation with native species should focus on those areas of the riparian zone that contain appropriate substrates and microclimates. The planting of willows or conifers in native sedge meadows will likely result in failure or the creation of an unnatural, unsustainable plant community.

In addition to revegetation, a suite of silvicultural options to accelerate riparian forest development can be implemented. Creation of small canopy gaps, small clearings, and placement of coarse wood debris on the floodplain to serve as nurse logs can enhance growth rates of existing trees or provide conditions for establishment of desirable trees. Overstory manipulations should be done in a patchy, irregular manner to mimic natural disturbances and forest structure. In some instances, the products of thinning can be used as a source of instream wood or nurse logs. Prescribed burning also can be an important activity when used to mimic the disturbance regime of natural fires.

Appropriate livestock grazing management is of major importance for the proper functioning of many western riparian zones, particularly where grazing is deemed a primary use (e.g., private ranch lands). While some have suggested that livestock can be used as a "tool" in riparian enhancement, there is no ecological basis to indicate that livestock grazing, under any management strategy, can accelerate riparian recovery more rapidly than total exclusion (Platts 1991; Elmore and Kauffman 1994). The passive restoration approach of livestock exclusion demonstrably has resulted in a rapid recovery of riparian vegetation (U.S. General Accounting Office 1988; Beschta et al. 1991; Kauffman et al. 1993); however, less is known regarding rates of channel morphology recovery (T. McDowell, University of Oregon, personal communications). Although moderate levels of winter grazing, late-season (autumn) grazing, or early-season (spring) grazing have been demonstrated to reduce harm by livestock in some riparian zones (Platts 1991; Elmore and Kauffman 1994), any grazing practice must include close monitoring of wood use and bank conditions so that livestock can be promptly removed before significant damage occurs. The variety of approaches to active restoration is potentially large and beyond the scope of this document, but what is important regarding active restoration procedures is that any approach reestablish the disturbance regimes and conditions so natural hydrologic, geomorphic, and biotic processes can occur. In some cases, active restoration may require removing or altering artificial structures contributing to degradation or preventing natural ecosystem processes from occurring. These practices might include obliterating roads that are contributing excessive amounts of sediment, removing instream or streambank structures (e.g., rip-rap, gabions, and anchored structures) that limit channel dynamics, reconfiguring channelized reaches to increase their sinuosity and floodplain connectivity, and removing mainstem dams to eliminate barriers to fish migration.

Instream Structures

A general deficiency of large, woody debris within streams draining forested watersheds is common throughout much of the Pacific Northwest, primarily because of historical practices of timber harvesting of riparian forests, splash damming, agricultural conversion, livestock grazing, and stream "cleaning" (i.e., the purposeful removal of wood debris). The natural recruitment of coarse, woody debris in such streams often requires much time (Gregory and Ashkenas 1990). As a result, managers often add large, woody debris. Where such practices are needed, the primary goal should be to provide natural amounts, types, sizes, and spatial distributions of wood both in and along stream channels. During the inevitable high-water events that follow, added wood should function effectively in channel development and sediment and hydrologic routing (Gregory and Bisson 1997). Managers should place logs in or along channels so they resemble natural accumulations of debris, and should use complex wood debris (e.g., whole trees with branches and root wads if at all possible) to maximize habitat values and minimize potential for movement. The placement should enhance conditions that facilitate natural establishment of woody species (e.g., point-bar formation or nurse logs) so wood recruitment will become a self-perpetuating process. Anchoring or cabling complex pieces should be done sparingly, if at all, because it does not allow for the natural behavior of log accumulations during high-flow events. In this respect log length is critical; logs longer than the active channel width are not likely to move very far downstream (Lienkaemper and Swanson 1986).

Unfortunately, structural additions to channels (e.g., logs, boulders) are too often undertaken before anthropogenic impacts causing degradation have been eliminated or before significant natural recovery of riparian plant communities has occurred. In both situations, artificial structural additions are premature and can cause additional degradation to riparian and aquatic ecosystems. Of particular importance is the concern that placement activities should not diminish the natural regrowth capacity of riparian forests and should not severely curtail or accelerate natural channel dynamics such as channel migration, pool development, and streambank building. Riparian and stream ecosystems degraded from off-channel activities cannot be restored by focusing only on manipulations within a channel.

Throughout the western United States, inchannel placement of habitat structures has become one of the most common and widespread stream "enhancement" activities. Although instream structures have been commonly used in attempts to control channel erosion and rehabilitate fish habitat since the early twentieth century (Elmore and Kauffman 1994), systematic evaluation of their success has been limited. Furthermore, instream habitat handbooks (e.g., U.S. Forest Service 1952; Seehorn 1985, 1992) generally provide no ecological or geomorphic perspective as to where various habitat manipulations are appropriate (or inappropriate). A summary of instream enhancement projects throughout the region (Beschta et al. 1994) indicated little or no positive fisheries response to structural approaches. Clearly, the widespread practice of engineered structural modifications to streams with little or no scientific evidence of biological benefits represents a management paradox of immense proportions.

Misinterpretation of Ecosystem Needs

Active restoration should be undertaken to facilitate recovery of natural ecosystem processes (Kauffman et al. 1995). Riparian and instream activities that do not address ecosystem function and linkages are likely to fail or even exacerbate degradation of the ecosystem-a result of misinterpretation of ecosystem needs. Examples of such misinterpretation might include outplanting hatchery fish of nonindigenous genetic strains and introducing nonnative plant species. Implementation of riparian or inchannel activities that further degrade or prevent reestablishment of hydrologic, geomorphic, or biotic functions also represents a misinterpretation of ecosystem needs (Figure 3). Such activities may involve habitat manipulations such as blasting bedrock channels; adding logs and boulders in

Ecological restoration is a holistic approach not achieved through isolated manipulations of individual elements but through approaches ensuring that natural ecological processes occur...

channels formed in floodplains of finely textured meadow systems; implementing in-channel engineering approaches that are heavily anchored by cable, metal rods, or boulders (structures that rely on geotextile fabrics to maintain their integrity); armoring streambanks with large boulders; and placing excavated sediments on streambanks and floodplains. Many of these approaches not only severely limit the capacity for streams to undergo natural adjustments in channel morphology and stream sinuosity through time, but they also may create conditions that suppress or stop the recovery of riparian vegetation.

Unfortunately, misinterpretating ecosystem needs is common with many instream rehabilitation and enhancement programs (Beschta et al. 1991; Kauffman et al. 1993). Stream manipulations targeted to fish habitat enhancement often exacerbate riparian and stream degradation for many reasons (Beschta et al. 1994):

- An inadequate understanding of riparian and stream ecology, particularly how stream-side vegetation and disturbance patterns shape both channels and habitat features;
- Sociopolitical pressures (e.g., it is socially or politically unacceptable to change ongoing land use practices that are causing degradation);
- Institutional limitations regarding the use of available funds (e.g., appropriations are designated only for mechanical or engineering approaches to stream manipulation with little or no appreciation of the effectiveness of improved stewardship);
- Management philosophies that emphasize immediately quantifiable project results (e.g., the number of instream structures built during a fiscal year) rather than ecological improvement or improved stewardship;
- Emphasis on a "landscaping" approach (e.g., designing channels or building structures based on preconceived plans rather than addressing factors limiting the processes that create these habitat features);
- A presumption that engineering approaches (e.g., placement of boulders, woody debris, gabions,

spawning gravels) are equivalent or superior to natural processes and structure;

- A presumption that inchannel structures can mitigate for riparian and aquatic degradation caused by land use practices (e.g., installing structures while allowing continued overgrazing, logging, or agricultural or industrial practices); and
- Current paradigms of land stewardship (e.g., a lack of a social or political land ethic that implicitly recognizes the value of natural or noncommodity products associated with naturally functioning and intact riparian ecosystems).

The rationale behind these reasons forms a common managerial paradigm: Stream, riparian, and fish habitat degradation brought about by anthropogenic activities, both locally and throughout a watershed, can be remedied solely through inchannel habitat manipulations. We suggest that the philosophy that natural habitat structure can be "improved" by engineering approaches misinterprets ecosystem needs and is an inadequate solution for fish habitat restoration. These approaches include activities that attempt to enhance fisheries habitat by eliminating natural barriers to fish passage, placing structures in intact ecosystems (old-growth forests), and putting spawning gravels or structural features such as logs or boulders in reaches where they would not naturally exist. Such activities not only carry a high risk of biological failure, but also risk a loss of capital resources, labor resources, and public credibility.

Sustainable and successful ecological restoration of degraded riparian systems is most likely to be achieved by considering the potential influences of proposed activities. Prior to the implementation of instream or riparian manipulations, the following questions should be addressed:

- Has passive restoration (e.g., changes in grazing, logging, etc.) been implemented, monitored, and evaluated prior to choosing structural manipulations?
- Will manipulations ultimately provide shade and thermally moderate stream temperature?
- Will they ultimately provide allocthonous inputs similar to that of stream-side vegetation?
- Will they ultimately provide the range of microhabitats typical of a particular stream?
- Will activities facilitate restoration of riparian vegetation that will restore natural channel morphology (e.g., overhanging banks, width-to-depth ratios, pool/ riffle morphology)?
- Will they decrease time-rate dissipation of a stream's potential energy (i.e., stream power) by providing increased flow resistance from stream-side vegetation along a reach as compared with energy dissipation at localized points associated with inchannel structures?
- Will they allow for increased channel sinuosity from increased hydraulic roughness (as would occur with recovery of riparian vegetation)?
- Will biogeochemical and nutrient cycling influences on water chemistry-the results of the unique functional linkages between hydrologic and biotic features of intact riparian zones-be preserved or restored?
- Will the activities improve woody-debris recruitment and, hence, channel diversity because of enhanced vegetation establishment and growth?
- Are the restoration activities composed of naturally occurring materials? Are their characteristics and functions within the natural context of the riparian and stream reach to be treated?

Conclusions

Riparian zones are rich ecosystems in terms of biological diversity, unique biogeochemical processes, and productivity. For humans, riparian and stream ecosystems are a foci of commodity, recreational, and aesthetic values. The preservation and maintenance of intact riparian ecosystems and the restoration of degraded ones are important to local, regional, and global societies as well as to future generations.

While we recognize that ecological restoration sometimes comes at a high cost, we also note that ecological restoration is an investment in the natural capital of stream and aquatic systems and, hence, the environmental wealth of the nation. Healthy riparian ecosystems are a subsidy of nature. Conversely, degradation is the squandering of this natural wealth through the depletion of the productive capacity of ecosystems. Clearly, restoring once-productive riparian and aquatic ecosystems in the western United States is in the best long-term environmental and economic interests of the nation. Restored riparian and aquatic systems essentially will be self-maintaining and, therefore, useful in perpetuity (Cairns 1993). Because these ecosystems are a fundamental component of our life-support system, restoration should represent an important priority for both public and private landowners.

Complex ecosystems and associated habitat features cannot be created via simple and artificial construction of selected components. Ecological restoration is a holistic approach not achieved through isolated manipulations of individual elements but through approaches ensuring that natural ecological processes occur (National Research Council 1992). If society is to use, enjoy, and benefit from the wide range of values and products associated with western riparian and stream ecosystems, concerted efforts of ecological restoration should begin before their productive potential, diversity, and beauty are forever lost.

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