INFLUENCE OF VALLEY FLOOR LANDFORMS ON STREAM ECOSYSTEMS[1]

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Abstract: A hierarchical perspective of relationships between valley floor landforms, riparian plant communities, and aquatic ecosystems has been developed, based on studies of two fifth-order basins in the Cascade Mountains of Oregon. Retention of dissolved nitrogen and leaves were approximately 2-3 times greater in unconstrained reaches than in constrained reaches. Both valley floor landforms and riparian plant communities influenced the abundance of primary producers. Abundances of cutthroat and rainbow trout in unconstrained reaches were approximately twice those observed in constrained valley floors. Valley floors are one of the most physically dynamic components of the landscape, incorporating major agents of terrestrial disturbance and fluvial disturbance. These corridors are major routes for the flux of water, sediments, nutrients, and species. Because of their unique properties, valley floors play an important role in landscape ecology.

Riparian zones occur at interfaces — ecological interfaces between different ecosystems and conceptual interfaces between different scientific disciplines. The plethora of definitions and delineations of riparian zones are inconsistent, confusing, and often contradictory, reflecting the diversity of disciplines, perspectives, and objectives from which riparian zones have been studied. Most riparian studies have examined selected facets of riparian ecology, but few have developed integrated concepts of the physical, chemical, and biological properties of the interface between aquatic and terrestrial ecosystems. The lack of ecosystem perspectives of riparian areas severely limits our understanding and proper management of these unique components of the landscape.

The weakness of ecosystem perspectives in riparian research is evidenced in the term "riparian ecosystems," a term frequently encountered in riparian literature. Riparian zones are interfaces between terrestrial and aquatic ecosystems and exhibit gradients in community structure and ecological processes of these two major ecosystems. Considering riparian zones as distinct ecosystems obscures the patterns of process and structure that are the basis for the great diversity of biota and landforms in riparian areas.

Most definitions of riparian zones for land management or ecological research are based on a few selected hydrologic, topographic, edaphic, or vegetative attributes of riparian areas. Riparian zones have been investigated from the perspectives of erosion control by riparian vegetation, phreatophyte ecology, uptake of nutrients or contaminants from groundwater, chemistry of water entering lakes and rivers, shading of headwater streams, effects on aquatic invertebrates, migration routes for wildlife, habitat for water fowl, and fish habitat. All of these subjects are critical aspects of riparian ecology, but it is important to recognize the constraints of concepts or definitions of riparian zones developed for specific sets of objectives.

In recent decades, ecologists and land use managers have recognized the importance of the structure and functions of riparian zones for both aquatic and terrestrial ecosystems (Knight and Bottorf 1984, Meehan and others 1977, Swanson and others 1982). Meehan and others (1977) defined riparian vegetation as "any extra-aquatic vegetation that directly influences the stream environment". From an aquatic perspective, riparian zones are defined functionally as three-dimensional zones of direct interaction with aquatic ecosystems, extending outward from the channel to the limits of flooding and upward into the canopy of streamside vegetation (fig. 1). Examples of critical functions of riparian vegetation for stream ecosystems include shading, bank stabilization, uptake of nutrients, input of leaves and needles, retention of particulate organic matter during high flows, and contribution of large wood.

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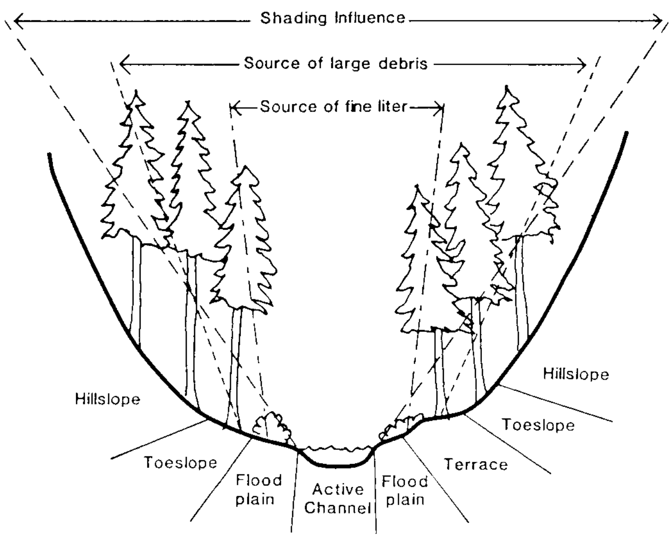

Figure 1– Riparian zone defined in terms of zones of influence of streamside vegetation on stream ecosystems (Meehan and others 1977).

Shading by streamside vegetation influences water temperature and aquatic primary production. Rooting of terrestrial vegetation within and adjacent to stream channels stabilizes banks and minimizes soil erosion. Living vegetation provides complex habitats for both aquatic and terrestrial wildlife. Leaves and needles provide essential food resources and habitat for aquatic insects. When floodplains are inundated, stems and roots of floodplain trees and shrubs comb organic matter out of transport and store it for subsequent processing on the floodplain or in the stream. Woody debris provides important structural elements that protect and stabilize stream banks, stores sediments that serve as habitat and spawning gravel, and traps organic matter that provides food for aquatic organisms. Dead woody material, both standing snags and wood on the forest floor, provides essential habitat for wildlife.

Most often management agencies adopt operational definitions of riparian zones that are based on hydric soils and unique terrestrial plant associations. If management agencies adopt perspectives of riparian zones that do not address critical ecosystem processes, the integrity of riparian resources cannot be insured. Integration of aquatic biological processes with physical templates of channel geomorphology and hydraulics has been a major challenge for stream ecologists in recent years. We present a hierarchical perspective of relationships between valley floor landforms, riparian plant communities, and aquatic ecosystems—an integrated ecosystem perspective of riparian zones.

Geomorphology of River Valleys

Flowing water interacts with the parent geology and inputs of organic and inorganic material from adjacent vegetation and hillslopes to form channels and floodplains within river valleys. Most geomorphic research has focused on lowland, floodplain rivers. In these alluvial systems, channel migration creates valley floor landforms and surfaces for development of riparian plant communities. The geomorphic dynamics of riparian zones in steep mountain landscapes involve both fluvial processes and mass movement events of adjacent hillslopes.

Valley floors contain both active channels and adjacent floodplains and terraces. Active channels are separated from adjacent hillslopes or floodplains by distinct topograhic breaks and commonly represent the lower extension of perennial terrestrial vegetation (Redman and Osterkamp 1982). *Floodplains* are relatively flat surfaces that are formed by fluvial deposition of sediments adjacent to active channels and are inundated during major floods. Several floodplain surfaces may occur within a valley floor; successively higher surfaces are flooded at less frequent intervals. In lowland valleys, floodplains are submerged much more frequently and for longer duration than floodplains in mountainous terrain. All floodplains and active channels are bordered by the lower flanks of adjacent *hillslopes*.

A *drainage network* extends from the headwaters to estuaries. *Sections* of a drainage network are differentiated by major topographic discontinuities, such as high gradient montane rivers, low gradient, lowland rivers in broad valleys, and broad coastal plains. Segments are continuous areas within a drainage formed by common large-scale geomorphic processes, and they have different potentials for development of active channels and floodplains.

A drainage segment is composed of *reach types*, delineated by the type and degree of local constraint imposed by the valley wall at the channel margin. The degree of local constraint controls the fluvial development of geomorphic surfaces. Constrained reaches (valley floor narrower than two active channel widths) occur where the valley floor is constricted by bedrock, landslides, alluvial fans, or other geologic features. Streams within constrained reaches are relatively straight, single channels with little lateral heterogeneity. River valleys in constrained reaches are narrow and include few floodplains. Consequently, riparian vegetation in these areas is similar in composition to adjacent hillslope plant communities.

Unconstrained reaches (valley floors wider than two active channel widths) are less constrained laterally and provide greater potential for floodplain development and active channel migration. Unconstrained reach types exhibit complex, braided channels and extensive floodplains, which support a diverse array of plant communities of different age. Riparian stands in these areas include many plant species adapted to frequent flooding.

Reach types are made up of sequences of *channel units*, representing different bed forming processes. Channel units in low gradient, sand and gravel bed streams are generally classified simply as pools and riffles (Leopold and others 1964). In high-gradient streams with coarser bed material, the distinction between high and low gradient units is conspicuous, but the steeper units may be divided into several additional types—rapids, cascades, falls. With the exception of abrupt falls, channel units are longer than one channel width and are distinguished on the basis of surface slope, degree of turbulence, and extent of supercritical flow.

Channel sub-units include hydraulic and geomorphic features shorter than the active channel width. Riffles, pools, rapids, and other features that are shorter than one channel width are categorized as sub-units. Backwaters, eddies, and side channels are also sub-units and play a distinctly different ecological role than sub-units along the main axis of the channel. Sub-unit features correspond to the habitat types employed in most aquatic ecological research. As flow increases and the active channel is completely inundated, channel units attain uniform surfaces and delineations between sub-units are obscured.

Riparian Vegetation

Riparian zones are extremely patchy, reflecting past fluvial disturbances from floods and non-fluvial disturbances of adjacent hillslopes. Fluvial processes are the dominant disturbance in riparian areas, but fire, wind, landslides, drought, freezing, disease, insects, and other natural agents of mortality common on upper slopes may influence riparian stands along valley floor. Furthermore, topoedaphic conditions of valley floors are extremely varied, ranging from continuously wet to extremely dry over short distances. Consequently, riparian plant communities are structurally and taxonomically diverse.

In conifer forests of the northwest, riparian plant communities exhibit greater diversity than plant communities of upper hillslopes. In riparian plant communities ranging from recent clearcuts to old-growth forests in excess of 500 years in Oregon, riparian communities contained approximately twice the species richness observed in upslope communities. Similar contrasts in species richness between hillslope and riparian areas were found in plant communities of the Sierra Nevada in California (table 1). Patterns of disturbance, particularly flooding, influence the spatial complexity of riparian plant communities, while environmental gradients, such as light, temperature, and moisture, determine the sharpness of transitions between riparian and hillslope plant communities.

Table 1 - Number of plant species per plot in riparian zones of the Cascade Mountains of Oregon and the Sierra Nevada of California (Art McKee, personal communication).

	Number of Plant Species	
Location	Upland	Riparian
Cascade Mountains		
McKenzie River	19-32	51-107
Sierra Nevada		
Sequoia National Park	28-38	51-55

Patterns of disturbance in riparian zones differ from disturbances on upper hillslope in shape and areal extent. Flooding in river valleys creates narrow, linear disturbance patches. The resulting floodplain forest is composed of thin bands of early seral stages, predominantly deciduous. Longitudinally, patches of riparian plant communities commonly are short and alternate from one side of the channel to the other. Within a flood event, the total area disturbed may exceed tens to hundreds of square kilometers, though the width of the disturbance at any point may be only a few tens to hundreds of meters. On a basin scale, the total area disturbed in a given flood may equal or exceed that of common terrestrial disturbances such as fire, wind, and disease. However, individual patches within the disturbed area in floods are small, relative to the overall disturbance, and extremely numerous. The heterogeneity imposed by flooding in river valleys contributes to the biological diversity of riparian areas.

Aquatic Ecosystems

Physical processes within riparian zones influence the biological organization and rates of processes of stream ecosystems. Active channels and floodplains form the physical habitat for aquatic organisms. Large organic matter contributed by riparian vegetation serves as a dominant geomorphic element, particularly in headwater streams (Swanson and Lienkaemper 1978).

Riparian vegetation supplies organic matter in the form of leaves, needles, and wood to streams and floodplains. This terrestrial source of organic matter provides a major portion of the food base for stream ecosystems (Cummins 1974). Leaves of herbs, shrubs, and deciduous trees have higher food value for most aquatic invertebrates than the more refractory needles of conifers (Triska and others 1982). Diverse riparian plant communities in broad floodplain reaches potentially offer higher quality food than conifer-dominated riparian zones, but the input of litter from deciduous plants is restricted to a shorter time interval in autumn. Thus, mature conifer forests provide a more consistent but lower quality food supply to stream ecosystems (Gregory and others 1987).

The canopy of streamside forests potentially shades the stream channel, decreasing solar radiation available for aquatic primary production. In small, headwater streams, riparian canopies strongly limit primary production, and as streams widen downstream, the influence of riparian vegetation on primary production decreases as the canopy opens over the channel. In this sense, the presence of riparian vegetation reduces aquatic productivity through the algal food base. Removal of riparian vegetation by man also increases solar radiation reaching headwater streams and potentially increases primary production. In Lookout Creek in the McKenzie River drainage, percent cover of filamentous algae was 3-30 times greater in a reach flowing through young second-growth riparian stand than a reach flowing through a 450-year-old old-growth stand. The influence of riparian canopy cover on aquatic primary production is most pronounced in headwater streams and diminishes downstream as the opening over the stream increases with increasing channel width. As a result, the effects of riparian timber harvest on aquatic primary production is relatively greater in headwater streams and decreases downstream. Algal food resources for aquatic organisms are much less abundant in streams than terrestrial litter but much higher in quality as food for invertebrates.

Food resources, whether aquatic or terrestrial in origin, must be retained in the stream before being consumed by aquatic organisms. Valley landforms and adjacent riparian plant communities directly influence bed form and channel roughness, which determine retention of water and both dissolved and particulate inputs during both low flow and floods. In two fifth-order basins in the Cascade Mountains of Oregon, we measured the retention of leaves in constrained and unconstrained reach types (reported by Lamberti and others in these proceedings). Leaves in transport in unconstrained reaches with broad floodplains were retained 4-5 times more efficiently than leaves in constrained reaches. Large logs and smaller branches and twigs supplied by riparian vegetation form complex accumulations, which increase the retention efficiencies of stream reaches. In streams of the Cascade Mountains, an average leaf traveled more than 12 m in reaches influenced by debris dams; but an average leaf traveled less than 5 m in reaches influenced by debris accumulations and less than 1 m in reaches that were completely obstructed by debris dams (Speaker and others 1984).

Riparian zones modify the cycling of dissolved nutrients as they are transported from hillslopes, across floodplains, and down drainages. In coniferous and deciduous riparian zones of Oregon, microbial transformation of nitrogen were greater in riparian areas than in upper hillslopes (Mike McClellan, Oregon State University, unpublished data). Rates of denitrification were more than five times greater in floodplains than adjacent hillslopes (table 2), and rates of denitrification were higher in alder stands than in coniferous forests. Because of the rapid cycling of nitrogen in the riparian zone, elevated concentrations of nitrate were not observed in streams in alder stands, even though nitrogen fixation was observed.

Table 2 — Rates of denitrification in riparian zones and upslopes in a 40-year-old deciduous and a 450-year-old riparian forest (expressed as ng N/g dry weight of soil/hr with standard errors in parentheses).

Site	Soil Depth	Geomorphic Surface Floodplain	Toeslope	Hillslope
Coniferous	0-15 cm	6.3 (2.2)	4.2 (4.2)	1.2 (1.2)
	0-30 cm	0.4 (0.3)	0.2 (0.1)	0
Deciduous	0-15 cm	15.0 (2.9)	8.2 (4.3)	3.0 (1.2)
	15-30 cm	11.3 (2.6)	1.4 (1.0)	1.2 (0.7)

Nutrient outputs from watersheds are not only modified within floodplain soils, but nutrients are rapidly taken up and transformed by stream communities as well. In streams of the McKenzie River drainage, we measured uptake of dissolved ammonium in constrained and unconstrained reaches. Dissolved nitrogen (ammonium) was approximately 2-3 times greater in unconstrained reaches than in constrained reaches (reported by Lamberti and others in these proceedings). Unconstrained valley floors are more complex environments both geomorphically and hydraulically and retain water and dissolved nutrients longer, increasing the potential for biological uptake. In addition, unconstrained reaches may support more abundant algal assemblages, increasing the biological demand for nutrients. Uptake of ammonium in reaches of Lookout Creek in young second-growth riparian forests was more than twice the uptake observed in reaches flowing through old-growth forests (reported by Lamberti and others in these proceedings), reflecting the influence of primary producers on nutrient cycling.

Higher trophic levels are also influenced by valley landforms. In the two study drainages in the McKenzie River in Oregon, abundances of cutthroat and rainbow trout in unconstrained reaches (120-200 individuals/100 m) were approximately twice those observed in constrained valley floors (60-80 individuals/100 m) (reported by Moore and Gregory in these proceedings).

Unconstrained stream reaches contain broad floodplains with numerous eddies, backwaters, and side channels. In addition to the main channel, these complex channel forms create a greater diversity of fish habitats and provide numerous lateral refuges during floods. In contrast, constrained reaches offer few refuges in which to escape the torrential flows of winter floods. Unconstrained reaches in our study streams also contained greater numbers of trout fry than constrained reaches. Salmonid fry rear in shallow, low velocity habitats along the edges of streams and in side channels and backwaters, particularly those associated with complex floodplains (reported by Moore and Gregory in these proceedings). Thus, the complexity of broad floodplains is beneficial for rearing of new year classes of fish and survival for fish of all age classes.

Conclusions

From an ecosystem perspective, riparian areas are created and maintained through extensive interaction between valley landforms, succession of terrestrial vegetation, and the structural and functional responses of aquatic ecosystems. Geomorphic processes create the structure of stream channels and floodplains, which serve as physical templates for successional development of riparian vegetation. The structure and function of stream ecosystems are strongly influenced by the habitat and food resources provided by channel structure and streamside vegetation.

Resource management agencies are faced with the pragmatic problem of identifying boundaries on landscapes without abrupt demarcation. Although effective riparian management requires establishment of such riparian management zones, all managers must constantly remind themselves that their riparian management zones usually include only a portion of the interface between terrestrial and aquatic ecosystems. Recognition of the trade-offs inherent in any riparian management system requires ecologically robust concepts of riparian areas. Management concepts and definitions of riparian areas that exclude the physical, chemical, and biological interactions within the interface between terrestrial and aquatic ecosystem cannot insure the ecological integrity of one of the most physically dynamic components of the landscape. The riparian areas along river valleys experience many of the disturbances of upslope forests (e.g., fire, disease, insect outbreak, wind) as well as the unique disturbance associated with floods. Riparian areas are also interfaces between terrestrial and aquatic ecosystems, encompassing overlapping gradients in the physical and biological properties of these distinctly different ecosystems. As a result, riparian areas are one of the most physically complex and biologically diverse components of the landscape. In addition, riparian areas are major routes for the flux of water, sediments, nutrients, and plant and animals within drainage networks. Because of their unique properties, riparian areas play important roles in landscape ecology and resource management.

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