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5 Riparian Management in the 21st Century

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Management of streams, lakes, and wetlands in forest ecosystems represents one of the most revolutionary changes in forestry in the latter half of the 20th century. Prior to 1950, forest harvesting along streams and rivers differed little from upslope harvesting: forests were cut from the ridge to the stream's edge. Logging operations dragged logs down stream channels to landings at the bottom of harvesting units. From the late 1800s until World War II, lower reaches of northwestern watersheds were subject to log drives—artificial floods created to run logs down the rivers to mills (Sedell and Luchessa 1982, Sedell and Frogatt 1984). These practices delivered large amounts of sediment to streams, lakes, and estuaries, removed forest canopies and warmed water temperatures, altered habitats associated with wood and greatly decreased future sources of wood inputs, and simplified and narrowed floodplains. After 1950, resource managers in the Pacific Northwest and other regions increasingly expressed concerns over effects of logging on streams and anadromous salmonids. Today, there is widespread agreement that historical forest practices negatively altered the structure of aquatic ecosystems and decreased their productivity (Gregory et al. 1987, Hicks et al. 1991, Bisson et al. 1992, McIntosh et al. 1993, Botkin et al. 1995). However, there are still many unanswered questions about what forest practices are appropriate in riparian areas. These are central issues in ecosystem management.

This chapter addresses future directions in riparian management for the next century. Current trends are based on the momentum of policies that have emerged over the last four decades of the 20th century. Thus, the first part of the chapter describes current policies for managing riparian areas on private, state, and federal forests to provide a context for understanding future trends in the field. The second part of the chapter then explores elements of future riparian management.

Current Policies and Practices

Regional managers have recognized the importance of ecosystem perspectives for riparian practices, but the nature of riparian areas as interfaces between ecosystems has been obscured in many applications. Ecosystems are unique assemblages of communities and their environments: riparian areas are "ecotones" or interfaces between terrestrial and aquatic ecosystems. Sharp gradients in environmental conditions, ecological processes, and species across the transitional zone between terrestrial and aquatic ecosystems make riparian areas one of the most diverse and dynamic portions of forested landscapes (Naiman et al. 1988, Gregory et al. 1991). Inaccurate designation of the land–water interface as a riparian ecosystem has obscured the ecological importance of these gradients. Riparian areas are broad interfaces with no discrete boundaries. The term "riparian management zone," however, represents distinct spatial boundaries that are designated to achieve specific management goals (Figure 5.1). Such management designations incorporate inherent tradeoffs between proportions of riparian functions included within and outside their boundaries.

Current federal and state riparian regulations are designed to minimize erosion, maintain stream shading, protect habitat conditions, maintain food resources, avoid detrimental environmental conditions, and maintain water quality. They are based on regional studies that have demonstrated that forest practices—including timber harvesting, yarding, and road building—alter many components and processes of aquatic ecosystems and the land–water interface. Forest harvest practices cause alterations in aquatic ecosystems or riparian processes, including changes in sedimentation and mass failure, stream temperatures, hydrologic regimes, channel structures, floodplain processes, amounts of woody debris, aquatic plant production, terrestrial litter inputs, and invertebrate, fish, and wildlife populations. These interactions have been evaluated and synthesized in several major symposia, reports, and books (Krygier and Hall 1971, Iwamoto et al. 1978, Newbold et al. 1980, Schlosser and Karr 1981, Harmon et al. 1986, Murphy et al. 1986, Salo and Cundy 1987, Raedeke 1988, Murphy and Koski 1989, Meehan 1991, Naiman 1992, Peterson et al. 1992, FEMAT 1993, Murphy 1995). These works provide detailed reviews of the effects of forest practices on aquatic ecosystems and variation in watershed and ecological responses observed across the Pacific Northwest.

Reviews of riparian management practices frequently focus on existing rules and regulations. They evaluate current practices in terms of protecting aquatic resources and incorporating fundamental ecological processes. While this perspective is relevant to analyses of future trends in riparian management, it poorly reflects the current state of forested landscapes in the region, the influence of riparian practices, and the absence of streamside protection prior to 1970. The emphasis on timber harvesting on federal lands in Oregon and Washington largely emerged after 1960 (Figure 5.2). The total amount of timber harvested and the proportion of timber coming from public and private lands changed as much or more from 1940 to 1960 as in recent decades. These historical trajectories form the landscape basis for future trends. For example, more than half of Oregon's private forest lands were harvested prior to 1972 (as indicated by 20- to 100-year-old age classes in 1988) and the first requirements for any form of

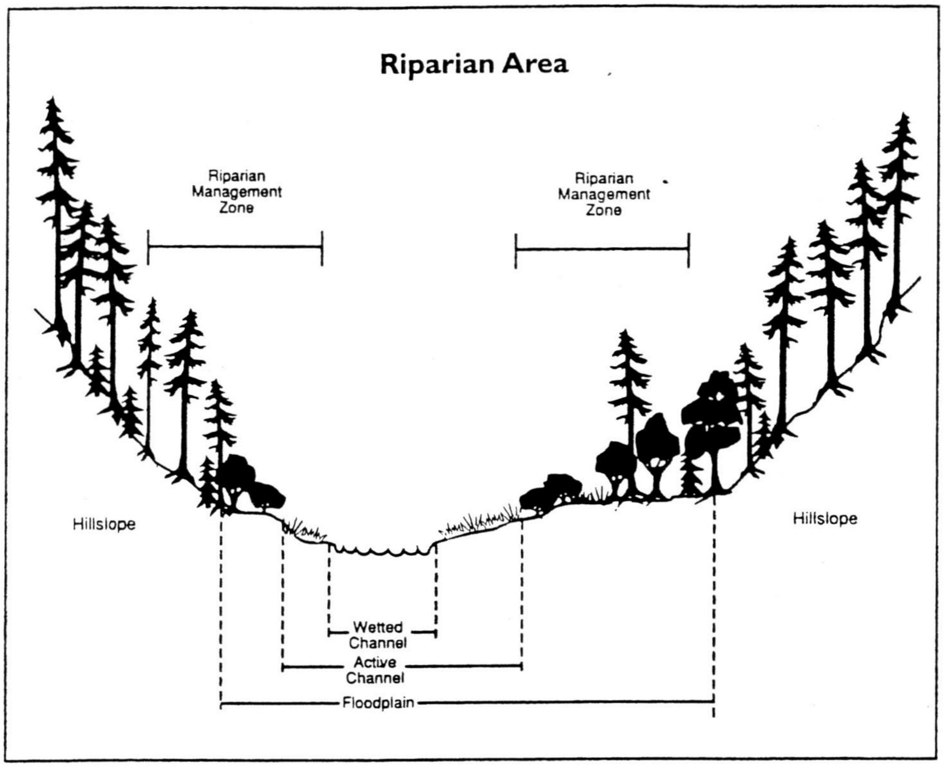


Figure 5.1 Cross-section of a riparian area and adjacent upslope forest. The riparian area may extend upslope, encompassing zones of influence for shading, leaf inputs, and wood delivery. The riparian management zone may be substantially narrower than the riparian area (from Gregory and Ashkenas 1990).

streamside protection (Gedney 1988). While recent changes in riparian management represent important advances, the landscape reflects more than a century of harvesting on all forest lands with little or no protection of riparian resources and aquatic ecosystems.

Current riparian management policies focus on several issues: (1) widths of riparian management zones, (2) retention of live trees and snags within the riparian zone, (3) the extent of shade cover, (4) floodplain protection, (5) yarding corridors, (6) culvert dimensions, (7) road crossings, (8) felling techniques, and (9) erosion protection. Riparian management practices for private and federal lands in the Pacific Northwest represent diverse approaches that have evolved for management of different types of land ownership since 1970 (Table 5.1). Most of the guidelines reported in this table have been established within the last five years; earlier riparian rules were substantially less protective.

The first question to emerge in riparian management is how wide should the riparian management zone be? This immediately raises questions of scale: What is the size of the stream, the height of the trees, and the lateral extent of riparian processes and habitats? Traditional approaches have (1) explored relevant ecological issues, (2) identified operational constraints, (3) debated tradeoffs between conflicting values, and (4) arrived at negotiated boundaries and harvest practices that fuel debate until the next revision of riparian rules. Frequently, the basis for selection of specific numerical criteria is not documented

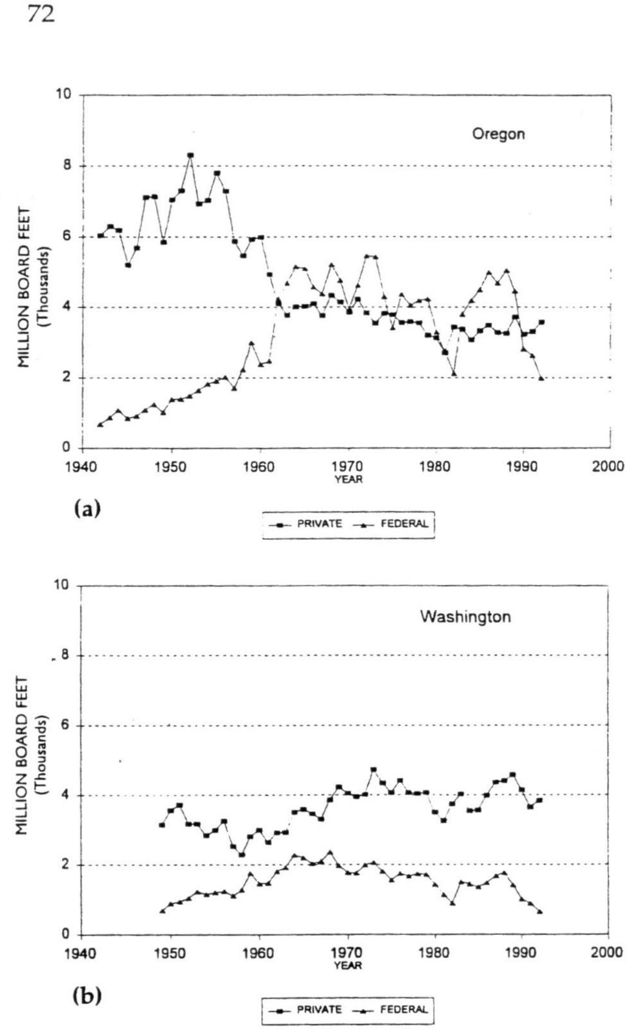


Figure 5.2 (a) Timber harvest from private and public forests in Oregon from 1940 to 1992 (from Oregon Department of Forestry). (b) Timber harvest from private and public forests in Washington from 1940 to 1992 (from Washington Department of Natural Resources).

and soon forgotten, thus insuring the starting point of the next revision—argument over the validity of numerical criteria.

Most riparian guidelines lack explicit determination of the reference conditions that represent the goals of future management. Identification of reference systems allows all parties to determine the validity of numerical standards and directs discussion over future revisions to the ecological intentions of management. Recent riparian management rules for the state of Oregon and the Northwest Forest Plan for federal lands set goals based on riparian forest conditions. In addition, federal land managers in the region have begun to match riparian zone widths to the nature of the riparian forest and its ecological interactions with aquatic ecosystems and to place riparian reserves with watershed and landscape contexts.

Federal Policies

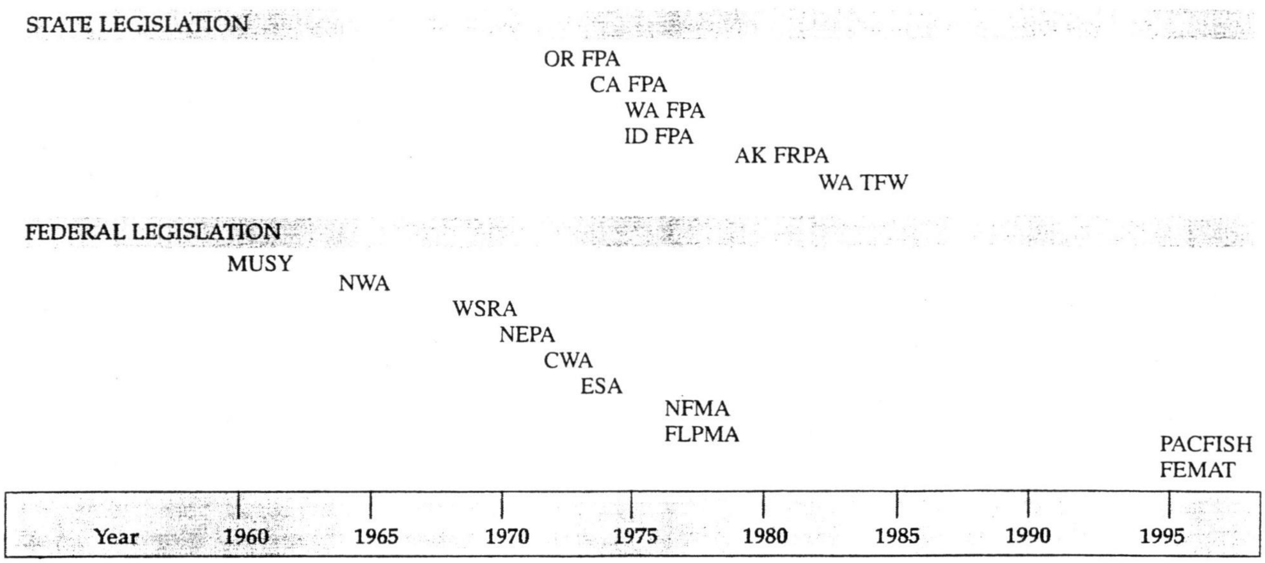
Explicit guidelines for riparian management have only emerged in recent decades. The sequence of federal and state legislation that embodies changes in streamside management reveals a rapid evolution of approaches for achieving ecosystem goals (Figure 5.3). Prior to federal legislation in the early 1960s, production of timber commodities was the primary goal of public forest lands. Hence, the burden of proof for protection of riparian resources rested on fisheries, wildlife, or hydrology specialists.

Federal land managers began to use buffer strips and riparian protection measures in the late 1960s following passage of the Multiple Use–Sustained Yield Act of 1960, which directed the Forest Service to address forest uses other than production of timber commodities, and the National Wilderness Act and the Wild and Scenic Rivers Act, which removed specific federal lands from the timber base for other resource values. Few specific guidelines governed the management of federal riparian areas, however, until passage of the National Forest Management Act and the Federal Land Policy and Management Act of the mid-1970s. These laws required the U.S. Forest Service and the Bureau of Land Management to conduct forest planning with specific attention to relevant federal laws, such as the National Environmental Policy Act, the Clean Water Act, and the Endangered Species Act. At this point, federal forest management agencies identified protection of riparian resources as the primary objective of riparian management. Moreover, they specified that managers should "give preferential consideration to riparian-dependent resources when conflicts among land-use activities occur" (USDA and USDI 1994). This represented a major shift of the burden of proof from ecologists to timber managers, and, in theory, it required timber harvesting to be justified because of its inherent

Table 5.1 Riparian management regulations for state and federal forests in the Pacific Northwest

Agency Class	Definition	Width (ft.)	Linear Density (Trees/1,000 ft.)	Site Goal (Stand)	Harvest	Floodplain	Bank Protection
Oregon							
Type F I	> 10 cfs, with fish	100	40 conifers	Mature 159 ft.^{2}/acre	Partial	None	20-ft. No harvest
Type F II	2–10 cfs, with fish	70	30 conifers	Mature 159 ft.^{2}/acre	Partial	None	20-ft. No harvest
Type F III	< 2 cfs, with fish	50	Deciduous	Mature 159 ft.^{2}/acre	Partial	None	20-ft. No harvest
Type N-D	< 2 cfs, no fish	0	Understory	0	Complete	None	N/A
Washington							
Type 1 & 2	> 75 ft.	100	50 trees		Partial	None	
Type 1 & 2	< 75 ft.	75	100 trees		Partial	None	
Type 3	> 5 ft.	50	75 trees		Partial	None	
Type 3	< 5 ft.	25	25 trees		Partial	None	
Type 4	> 2 ft.	25	0		Partial	None	
California							
Class I	Fish present	150	25% of conifers		Partial	None	
Class II	Fish within 1,000 ft.	100	25% of conifers		Partial	None	
Class III	No fish	Site-based	50% understory		Partial	None	
Idaho							
Class IA	> 20 ft., with fish	75	67 trees		Partial	None	
Class IB	10–20 ft., with fish	75	63 trees		Partial	None	
Class IC	< 10, with fish	75	42 trees		Partial	None	
Class II	No fish	5	0				
Alaska							
Type A	Anadromous fish, Unconstrained	66	All trees		No harvest	None	
Type B	Anadromous fish, Constrained	100	BMP		BMP	None	
Type C	No anadromous fish	50	BMP		BMP	None	
FEMAT							
Class I	Fish-bearing	300/2 spt	All trees	Old growth	No harvest	Protected	No harvest
Class II	Permanent, no fish	150/1 spt	All trees	Old growth	No harvest	Protected	No harvest
Class III	Seasonally flowing	100/1 spt	All trees	Old growth	No harvest	Protected	No harvest
PACFISH							
Class I	Fish- bearing	300	All trees	Old growth	No harvest	Protected	No harvest
Class II	Permanent, no fish	150	All trees	Old growth	No harvest	Protected	No harvest
Class III	Seasonally flowing	100	All trees	Old growth	No harvest	Protected	No harvest

Note: Many states have multiple standards based on regional, stand, topographic, morphological, and biotic criteria. Representative standards are presented to illustrate the general characteristics of the state and federal approaches to riparian management. All states and federal agencies include various provisions for alternative practices, waivers, and experimental applications.



State Legislation

OR FPA	Oregon Forest Practices Act of 1972
CA FPA	California Forest Practices Act of 1973
WA FPA	Washington Forest Practices Act of 1974
ID FPA	Idaho Forest Practices Act of 1974
AK FRPA	Alaska Forest Resources and Practices Act of 1978
WA TFW	Washington Timber, Fish, and Wildlife Program of 1984

State Legislation

MUSY	Multiple Use-Sustained Yield Act of 1960
NWA	National Wilderness Act of 1964
WSRA	Wild and Scenic Rivers Act of 1968
NEPA	National Environmental Policy Act of 1970
CWA	Clean Water Act of 1972
ESA	Endangered Species Act of 1973
NFMA	National Forest Management Act of 1976
FLPMA	Federal Land Policy and Management Act of 1976
PACFISH	Pacific Anadromous Fish Habitat Management Strategy 1994
FEMAT	Forest Ecosystem Management Assessment Team, ROD 1994

Figure 5.3 History of state and federal legislation related to riparian management practices in the Pacific Northwest.

modification of riparian and aquatic systems. However, in reality, riparian protection and harvesting practices in forest plans varied widely between national forests. Consistent guidelines for riparian practices still do not exist at a federal level. Regionally consistent riparian practices have been established only since 1994 on federal forests (USDA and USDI 1994, PACFISH 1994).

State Policies

Federal land-management policies established an emerging set of environmental considerations in riparian areas, and the water quality standards of the Clean Water Act created the motivation for defining appropriate management practices on private and state lands in the Pacific Northwest. Oregon implemented the first Forest Practices Act for state and private lands in 1972. Other western states quickly developed similar riparian regulations (Figure 5.3). Early state laws contained few requirements for the maintenance of larger size classes of either coniferous or deciduous trees and were designed primarily to provide stream shading and erosion control. Few other environmental or ecological functions of riparian areas were even considered in the early determination of riparian management guidelines.

All states in the Pacific Northwest define a range of appropriate riparian management practices for private and state forests. These standards are modified for local conditions based on a variety of criteria related to regional location, stand types, topography, channel or valley morphology, and fish communities. Approaches vary from state to state, and flexibility for site-specific management is provided in several ways. Some states, such as Oregon, have developed extensive criteria for management practices, although landowners can ask for site-specific exceptions. Washington uses an innovative system of basin analyses and coordinated development of basin-specific practices based on local consensus (known as the Timber, Fish, and Wildlife Program; see Smith, Chapter 27). It is still not known whether specific rule-based approaches or consensus models will be most effective. As such, the diversity of riparian practices on state and federal lands in the Pacific Northwest may be one of the strongest assets for future development of effective riparian management.

The FEMAT Report

In 1993 the Forest Ecosystem Management Assessment Team (FEMAT), convened by President Clinton, developed a range of options and a recommended alternative for ecosystem management of federal forests within the range of the northern spotted owl (FEMAT 1993). The FEMAT report proposed several major advances in the management of aquatic ecosystems. First, it called for the creation of key watershed and riparian reserves designed to fulfill upslope as well as riparian functions—in contrast to previous strategies geared toward the protection of selected habitats or species of interest. Second, it provided a spatial context for delineating riparian reserves based on forest–stream interactions rather than fixed riparian widths. And finally, the FEMAT report recommended that watershed analyses be conducted to identify conditions that influence the ability of a particular landscape to meet established ecosystem management goals.

The FEMAT report's designation of key watersheds was one of the first attempts to incorporate a network of watersheds into an ecosystem management plan at a landscape scale (Pacific Rivers Council 1993). The physical and ecological processes in watersheds serve as a foundation for more-site-specific conditions and selection of management alternatives. Watersheds that contain critical aquatic resources and habitats were selected to provide refuges and sources of colonists at a scale relevant to river networks and components of upland terrestrial ecosystems.

Riparian reserves were established to (1) protect riparian-dependent resources and aquatic ecosystems and (2) provide habitat for and fulfill the environmental requirements of upslope communities of plants and animals. An innovative and ecologically sound feature of these riparian reserves was the scaling criterion developed for delineating their boundaries. Instead of lapsing into the traditional debate over the width of the riparian management zone, boundaries were based on "site-potential tree heights." A site-potential tree height is the average height of trees that have attained the maximum height possible given the site conditions. This delineation of riparian widths is based on functional interactions between riparian forests, stream processes, and microclimate. Unlike previous definitions of riparian management zone boundaries, this definition is transferable to other forest types and locations and is linked directly to ecological function.

The term "riparian reserves," however, only conveys a portion of their intended purpose—they were designed to fulfill both upslope and riparian functions in ecosystem management. To fulfill both of these functions, riparian reserve widths of two site-potential tree heights were established along fish-bearing streams, and widths of one site-potential tree height were established along either perennial non-fish-bearing streams or along ephemeral streams. Riparian reserves outside lands withdrawn for other purposes represent an estimated 2.628 million acres of the 24.455 million acres of federally administrated forest lands within the range of the northern spotted owl—or 11 percent of the land base (USDA and USDI 1994). Total reserved or withdrawn lands (i.e., wilderness, national parks, late successional reserves, other administratively withdrawn lands, riparian reserves) account for 18.856 million acres or 77 percent of the total land base. Following watershed analysis, forest practices within riparian reserves can be modified to attain the overall goals of the Northwest Forest Plan. In concept, these practices could include preservation, silvicultural restoration, modification of boundaries, and testing of alternative forest practices—as long as the status of populations and communities in these forest ecosystems is not jeopardized.

The FEMAT report defined a new context for riparian management at the landscape scale. Future consideration of alternative riparian practices will be scaled by links between ecological functions and adjacent forests as well as the roles of key watersheds within the larger landscape identified in the Northwest Forest Plan.

Future Directions

Over the last 30 years, many unprecedented advances have been made in riparian forest practices in the Pacific Northwest that far exceed those of other regions of the United States and Canada. Changes in riparian management represent trends rather than arrival at an endpoint—an issue raising strong feelings on both sides in the political debate over the future of forest management in the region. Where are these changes leading? Why will riparian management change even more in the next century than the abrupt changes that we have witnessed at the end of the 20th century? Part of the answer lies in the diversity of riparian management approaches that have emerged as we move into the next century. Resource managers and planners in the Pacific Northwest are simultaneously pursuing several fundamentally different social and ecological models rather than a single uniform path. Though these paths may evolve in parallel, the wide array of land ownerships, ecosystem types, and changing demographic patterns will translate into complex goals and management practices for riparian resources within the region.

Future trajectories of change in riparian practices reflect several emerging characteristics of ecosystem management:

- An emphasis on ecological function and natural forest pattern
- Adoption of a landscape perspective of river networks
- Development of ecologically sound systems for restoring ecosystem properties
- Attention to social needs for riparian resources

These trends in riparian management are dynamic—no one can accurately predict the outcome of ecological, environmental, social, economic, and political interactions. Though the endpoint is not clear, the influences of these factors will shape the course of riparian management in the 21st century.

An Emphasis on Ecological Function and Natural Forest Pattern

In contrast to early riparian management systems, which focused on one or two characteristics of concern (e.g., sediment or stream temperature), newer systems on both public and private lands have evolved rapidly to address the full range of ecological functions that occur at the land–water interface (Salo and Cundy 1987, Raedeke 1988, Gregory et al. 1991, Naiman et al. 1992, Thomas et al. 1993). Revision of state forest rules after 1990 throughout the region include analyses of shade, food resources, woody debris, channel dynamics, sedimentation, mass failure, hydrologic regimes, and invertebrate, fish, and wildlife populations. These ecological functions are used to set management boundaries and determine alternative practices. One result of this shift toward a functional definition of riparian zones is the development of functionally based scalers for riparian boundaries, such as the site-potential tree height criteria in the Northwest Forest Plan. This is not to suggest that federal and private forest lands will adopt identical standards; rather, a common conceptual basis will evolve for guidelines for riparian forest management

Development of a functional basis for delineation of riparian management zones will necessitate explicit identification of reference conditions that represent the goals of riparian practices. Oregon recently established mature forest conditions at the midpoint of rotation as a target or reference condition for its revised riparian rules (Oregon Department of Forestry 1994). An accepted reference system for desired management outcomes provides a common basis for interpretation of the appropriate numerical criteria, potential areas for future modification of the rules, and a standard against which to measure management success. Numerical standards without such a context fuel controversies and hinder widespread development of alternative approaches. Future reviews will determine whether an adopted reference system is consistent with the goals and objectives of a particular management agency or with new legislation; revisions can then be made to reflect the changing base of scientific information.

Floodplains are a fundamental ecological component of stream ecosystems that are vital to the survival, recolonization, and productivity of aquatic communities (Junk et al. 1989, Bayley 1995). Only federal riparian policies specifically protect floodplain functions (Gregory and Ashkenas 1990). None of the forest practices acts of the northwestern states specifically identifies floodplain areas within riparian management zones, and floodplain processes are not directly addressed in riparian practices. All states have provided for protection of adjacent wetlands, but a floodplain has to be identified as a wetland before any level of protection is required. Although the fundamental role of floods on aquatic ecosystems (Junk et al. 1989), hydrologic regimes, floodplain structure, and human communities (Booth 1991) has been incorporated in floodway management for decades, private forest managers have actively avoided this aspect of forest ecosystem management. Recurrence intervals of major floods range from 50 to 200 years, well within the rotation ages of managed forests; thus consideration of flood processes and floodplains is essential for sound forest management.

Development of approaches that provide riparian functions for terrestrial wildlife presents several challenges for riparian management (Raedeke 1988, Thomas et al. 1993). Assemblages of terrestrial wildlife within a watershed exhibit varying degrees of association with riparian areas, ranging from obligate dependence to almost complete avoidance. Moreover, these relationships may shift seasonally based on moisture availability and life history requirements (Raedeke 1988, McComb et al. 1993). Wildlife dependence on riparian resources extends over diffuse gradients extending well into upslope terrestrial environments. Simple riparian interactions such as shading, inputting of woody debris, and inputting of leaf material have few parallels in wildlife–riparian habitat relationships. As a result, ecological studies of terrestrial wildlife tend to focus on species-specific patterns and ecological requirements. More general functional group or guild approaches used for aquatic ecosystems (Cummins 1974) have not been applied effectively to wildlife, in part because of the variability of wildlife–habitat relationships. Large networks of riparian reserves—such as those recommended in the Northwest Forest Plan that have widths of one site-potential tree height along ephemeral streams—reflect the commitment of larger land areas than commonly found in a riparian delineation for basin-wide wildlife protection. Alternative approaches (e.g., intensive survey, dynamic modeling, species-specific management, experimental monitoring, and long-term monitoring) may shift the emphasis away from riparian reserves. However, the time and personnel required to build adequate information bases are enormous.

One of the major limits of current riparian management is the lack of information on the structure and stand dynamics of riparian forests and their role in larger landscapes (Agee 1988; see also Spies, Chapter 2). Almost all considerations of riparian forest dynamics—regeneration, growth, survival, mortality, snag development, down wood delivery, community succession, and rates of succession—are based on assumptions derived from upslope forests. The unique gradients of light, moisture, microclimate, and flood disturbance across riparian areas make it highly unlikely that these assumptions are valid. Studies of riparian forests have demonstrated that their composition differs greatly from that of upslope forests and often exhibits a much greater richness of terrestrial plant species and a lower volume of conifers (Schoonmaker and McKee 1988, Gregory et al. 1990, Ursitti 1991, Emmingham and Maas 1994). Until forest ecologists develop a more regionally and ecologically extensive body of knowledge on riparian forest dynamics, our management systems and silvicultural approaches will be limited by a high degree of uncertainty.

Current forest management is based on generating economically desirable forest stands as rapidly as possible within the constraints of relevant ecological goals. This strategy is applied to both upslope and riparian forests, either for commercial goals of the forest industry or for ecological goals of aquatic and terrestrial ecologists. Our ability to accelerate development of short-term economic goals is well demonstrated, but our ability to generate forest structures that are recognized and used effectively by species and communities is poorly developed.

Regardless of our ability to manipulate stand structure for economic or ecological goals, we face a fundamental long-term question: Are differences in rates of forest succession, either between riparian and upslope forests or across forest landscapes, important for long-term ecosystem function? Variation in rates of succession may have implications for the diversity of plant communities, the diversity of associated nonplant species, resilience to disturbance, habitat heterogeneity, nutrient flux, and microclimate (see Spies, Chapter 2). Riparian forests experience a broader suite of disturbances—including floods, landslides, fire, disease, insect outbreaks, and windthrow—which shape riparian patterns and create some of the most complex forest structures in the landscape. We have little documentation on rates of plant succession in natural or managed riparian forests. Riparian management in the next century will require a more robust knowledge of riparian stand dynamics and forest succession. In the meantime, our application of such essential concepts of ecosystem management will be severely limited.

Adoption of a Landscape Perspective of River Networks

A central question for managing forest ecosystems at the scale of landscapes has remained largely unasked, let alone unanswered: What patterns of future forest structure will be created by our management systems, and what are the ecological implications of these patterns? Private, state, and federal forest managers in the Pacific Northwest tend to create a "forest of walls" through their practices of both commodity harvest and ecological protection. Riparian and upslope management have been addressed as separate systems with separate goals; almost no attention has been paid to ecological links between upslope and riparian forests. Fire breaks, road systems, different levels of harvest between riparian and upslope forests, and other management practices create artificial patterns that have unique spatial characteristics of edge, patch dimensions, and connectivity not found in the natural forest landscape. Even the Northwest Forest Plan, with its extensive network of riparian reserves managed to maintain mature to old-growth forests along streams and rivers and restrict harvest to upslopes and ridgelines, will produce a forest pattern that differs markedly from the structure of forests across the landscape prior to harvest.

One of the most promising areas of riparian management in the next century will be the integration of upslope and riparian management at basin and landscape scales. In many ways, our conceptual and operational evolution of (1) recognizing the important ecological functions of riparian networks (Naiman et al 1993), (2) developing practices to maintain or restore varying degrees of those functions (Gregory and Ashkenas 1990), and (3) implementing a range of approaches across different forest ownerships has been a necessary precursor for future advances in applying riparian management to entire river basins.

There are several alternatives that are likely directions for future research and forest management (Botkin et al. 1995). First, we will need to explore the long-term consequences of our collective management systems in river basins. This will require remote sensing, spatial pattern analysis, dynamic forest models that operate at large scales, models of aquatic responses, and experimental studies to identify the mechanisms of physical and ecological responses. Second, we will need to acknowledge the degree to which specific landscapes can mimic natural forest patterns and identify more-effective approaches for different mixes of ownerships. The greatest potential for creating large-scale patterns that resemble long-term dynamic patterns like those that existed prior to timber harvesting will be in areas with extensive, contiguous public forests. Checkerboard ownership patterns of public and private lands offer the least potential because of the inherent differences in their resource management goals.

Historically, riparian management has focused on harvest units. This ignores the network properties of riparian areas within river basins and creates challenges for effective management. Fundamental decisions about riparian-dependent resources, their habitats, and physical processes must be addressed within the context of the river network (Naiman et al. 1991). Most current management strategies for commercial forest lands or national forests focus on montane portions of the landscape. As a result, lowland forests primarily occur in private nonforest ownerships. Although these riparian forests and floodplain rivers are critical components of a riverine ecosystem, they are not addressed through current riparian practices (Boule and Bierly 1987). Exploring alternatives such as land exchanges and public acquisition of these areas, which are essential to restoration of large river and aquatic productivity, is a high priority for future riparian management.

Development of Ecologically Sound Systems for Restoring Ecosystem Properties

Though forest practices have certainly improved, we are left at the end of the 20th century with a legacy of past practices and an obvious need to restore ecological characteristics of riparian forests (Pacific Rivers Council 1993). Concerns about realistic goals for restoration are certainly valid—it is virtually impossible to return forest ecosystems to the conditions that existed prior to Euro-American settlement. Even if it were possible, restoration might not reflect the changes that would have occurred over the last 200 years under natural conditions. But this is an extremely restrictive perspective of restoration that is not dynamic or appropriate for modern landscapes.

Restoration is the process of encouraging a system to maintain its function and organization without continued human intervention (NRC 1992). If a system has been shifted outside its range of performance under natural conditions, restoration attempts to move the system toward that range of performance in the future. The degree to which the system can reach that desired range of behaviors will depend on many factors—cause and degree of degradation, irreversibility of past actions or changes, viability of remaining populations, financial resources, and the time frame for desired recovery (Moyle and Yoshiyama 1994). Restoration should not be considered to be the return of a system to a fixed, pre-alteration condition (NRC 1995).

Ecosystem restoration inherently depends on a framework of broader landscape management that protects, maintains, and restores ecosystem structure and function (Wissmar and Swanson 1990, Sedell et al. 1991). Unfortunately, our recent history of riparian restoration, though well intended, has emphasized engineering approaches, which erect permanent "structures" in streams, establish administrative programs, and highlight paper trails and ledger-based accountability (Reeves et al. 1991, Frissell and Nawa 1992). Sound restoration of aquatic ecosystems requires a solid foundation of ecological principles and a clear recognition of the dynamic nature of streams, rivers, wetlands, lakes, and their adjacent riparian forests.

Several fundamental principles will guide effective restoration of watersheds, riparian areas, and aquatic ecosystems:

- The goal of ecological restoration is to reestablish the ability of the system to maintain its function and organization without continued human intervention.
- Restoration is no substitute for appropriate ecosystem management. Any restoration program should be nested within a larger program of landscape management that protects, maintains, and restores ecosystem structure and function.
- Resource analysis should precede any restoration effort. Resource evaluation should begin at least at the scale of the entire river basin, focusing down to a specific watershed, and finally addressing local reach characteristics. Specific habitat characteristics and ecological processes that have been degraded should be identified. Restoration practices should be designed to alter those factors that shape the ecological processes of concern.
- Before restoration efforts are implemented, practices that caused resource degradation must be changed to prevent or reduce continued environmental degradation. Constraints on current conditions and processes should be considered in determining the appropriate timing for restoration efforts. To the degree possible, systems should be allowed to stabilize before habitats are altered unless immediate and intensive efforts are required to save resources from extinction or prevent catastrophic habitat change.
- Restoration efforts should provide materials and organisms to reestablish natural physical and ecological processes. Material should be supplied in amounts and types that would be within the range expected for the system. Species or stocks of organisms should be native to the area and maintain the integrity of the genetic characteristics of local populations.

- The time frame for ecosystem restoration should be described explicitly, and expected patterns of recovery should be identified clearly.
- Actions should be reversible either by natural processes or by human correction, if possible.
- Restoration of streams and rivers should protect or restore floodplain and channel function and recover terrestrial plant communities.
- Natural disturbances such as floods, fire, windthrow, disease, and pest outbreaks are the major agents of restoration at the scale of river basins and forest landscapes. Resource management agencies need to develop after-the-disturbance policies that protect beneficial changes caused by natural disturbances. Disaster relief efforts that simply repeat previous resource management mistakes must be prevented.
- The success of restoration efforts should be evaluated based on ecological functions and responses within the dynamics of the system.

Understanding the current status of riparian forests, channel structures, and aquatic communities is essential to developing appropriate restoration objectives. All too often, projects are initiated without identifying specific objectives. For instance, pools are created for fish habitat without determining whether existing geomorphic and hydrologic processes would maintain additional pools over the long term, or whether existing fish populations are actually limited by lack of pools.

Conditions of existing riparian forests, stream channels, and aquatic communities must be identified both for the basin and for the restoration site (Reeves et al. 1991). Projects initiated without consideration of basin-level conditions will be more likely to fail than those based on network assessment. If possible, reference systems that represent desired future conditions should be located and examined to design restoration approaches. If natural areas cannot be found within the basin, similar basins nearby can be used to compare patterns found at the proposed restoration site. Location, distribution, configuration, and size of riparian or channel modifications should be consistent with the patch structure of the riparian vegetation and the geomorphic and hydraulic properties of the stream reach (Bottom et al. 1985). If a riparian area has been damaged by a natural or land-use-related disturbance, the probability of continued disturbance must be considered. Any attempts to restore ecological conditions can be negated by treating the symptom rather than the source of disturbance.

The majority of aquatic restoration efforts in the Pacific Northwest focus on restoring channel structure, particularly adding large woody debris, but long-term restoration of riparian functions (e.g., woody debris accumulation, shade provision, nutrient retention, food production for aquatic organisms) requires either natural riparian forest succession or silvicultural restoration. The goal of silvicultural management in riparian management zones should be to provide the natural ecological functions of riparian vegetation where past practices or natural events have diminished the diversity of riparian plant communities. All stages of silvicultural activity should encourage natural patterns of succession within the constraints of our current understanding of community composition, patch dimensions, and rates of succession (Agee 1988). Silvicultural operations in riparian areas can create diverse and structurally complex riparian plant communities (see e.g., Franklin et al., Chapter 7; Debell et al., Chapter 8; and Tappeiner et al., Chapter 9). Where short-term canopy recovery is required, hardwood species can be used to rapidly reestablish vegetative cover. Coniferous species can be used to reestablish long-term shade conditions and provide for more persistent wood in channels. Snags, green trees, and cull trees can be left in place to provide a short-term debris source. Native species that decay slowly can provide long-term sources of woody debris and snags. Salvage of trees and snags from riparian areas should be avoided unless it benefits riparian-dependent resources.

Reestablishment of shade over stream channels can be accelerated by protecting any remaining streamside vegetation, especially young trees. However, in areas dominated by shrub cover, underburning may encourage regeneration of desired tree species. Fire alters forest structure in upslope areas more frequently and more intensively than it does in riparian areas, but fire is a natural disturbance in riparian forests (Agee 1993). Exclusion of fire in riparian areas, both through overall fire suppression efforts and through riparian protection, produces riparian plant communities that do not reflect natural composition or patch structure. Incorporating a full range of natural disturbances within riparian forests may improve our ability to maintain ecosystem functions throughout river networks.

Based on analysis of riparian forest conditions within a basin, precommercial thinning may offer an opportunity to attain ecological goals of restoration and produce timber resources for human use. Stand thinning and underplanting can accelerate growth, increase structural complexity, replace native riparian species diminished by harvest, create snags, and provide large woody debris for the forest floor and stream channel. Placing thinned material directly into channels may increase short-term channel and floodplain complexity, particularly in small streams lacking debris. This small woody debris can provide structure and organic matter for 5 to 15 years. At the commercial thinning stage (40–80 years) there are two options: (1) the operation can be avoided completely in the riparian management zone, leaving natural mortality at 80 to 150 years to thin the area, or (2) commercial thinning can proceed, but pole timber and culls can be placed in the channel. Debris additions are appropriate if the stream channel contains inadequate volumes of woody debris; thus, site inventories are required to coordinate thinning operations with restoration objectives.

In degraded riparian areas, structural complexity and vertical diversity can be attained partially by leaving large, distorted, or broken trees in adjacent harvest units. These groups of trees outside the riparian management zone serve to feather the riparian forest into the adjacent younger forest and provide wildlife habitat. Group selection or single-tree selection is preferable to even-age management (Agee 1988). Thinning in riparian management zones should leave trees irregularly distributed in patches that reflect local patch dimensions and composition rather than uniformly spaced throughout the stand.

The major agent of restoration in riparian areas and stream ecosystems of the Pacific Northwest is floods. Restoration is a process of change, and most ecosystems change most dramatically during episodic disturbances (Swanson et al. 1990). Stream channels are shaped not during low flows, but during short-duration, infrequent floods. During these high flows, the stream has the power to move sediment, erode deep pools, deposit floodplain surfaces, create major debris dams, and shape the aquatic ecosystem (Gregory et al. 1991, Naiman 1992, Bayley 1995). Riparian areas serve as critical refuges and contribute large wood and boulders during floods and debris flows (Lamberti et al. 1991). Human efforts to restore streams and riparian areas will pale in comparison to the enormous forces of floods, which are the natural restoration process in stream ecosystems. Unfortunately, humans also eliminate many of the ecological benefits of floods in disaster-relief efforts and in repair programs after these basin-scale events. One of the most positive steps for future riparian restoration will be policies for systematic review of both social and ecological consequences of flood events and for maintenance of beneficial changes to the greatest degree possible.

Attention to Social Needs for Riparian Resources

People simultaneously abhor and desire regulations and legislation because of their conflicting needs for freedom and flexibility on one hand and assurance of safety and common good on the other hand. This dilemma clearly is central to riparian resource issues and future trends in riparian management over the next century. Far more regulatory requirements have been placed on the management of public and private forest lands in the Pacific Northwest than on other land-use types—a reflection primarily of the large portion of forest land in public ownership.

As our society develops laws that reflect its desires for managing its public resources, questions arise about their application to private lands. Common resources such as water, air, migratory fish, and wildlife make these questions relevant to society as a whole and encourage extension of practices from the public to the private land sector. What does this suggest for future trends in riparian management? A likely outcome of human demographics is increased regulatory guidance; concerns about fairness and equality may translate into application of riparian regulations to all land-use types.

A poll of forest land owners and managers would almost certainly call for reduced regulatory constraints. This feeling is understandable, but the outcome is unlikely. Increased human populations will have dual impacts on the forest industry. Human populations in the Pacific Northwest are increasing at 1.5 to 2.0 percent per year, resulting in a projected doubling of the population in 35 to 40 years (American Almanac 1994). First, there will be a greater demand for forest products because of the increased number of users. This effect will be amplified if recent trends in per capita consumption of wood continue; between 1970 and 1988, per capita consumption of wood products in the United States increased 30 percent from 61.1 cu. ft. to 79.5 cu. ft. (American Almanac 1994). Second, social demands for water resources, fisheries, wildlife, and recreation will increase due to the greater number of people using public land resources. Oregon and Washington currently obtain 42 percent and 35 percent, respectively, of their domestic water supply from specifically designated national forest lands (Bruce McCammon, Region 6, U.S. Forest Service, personal communication, 1994).

Though landowners would prefer the use of voluntary programs, incentive systems, user fee systems, market-based incentives ("green marketing"), and other less rigid regulatory approaches, these types of guidance have little history of success. The most direct and well-demonstrated tools for influencing collective human behavior in large systems have been regulations that define a range of appropriate actions. The major advances in riparian management in the Northwest to date have been based on such legislation, and there is little evidence that this trend will change.

One of the most glaring inconsistencies in riparian management in the Northwest is the enormous disparity between riparian management requirements on private forest lands and that on other land-use types. There are numerous examples of riparian management zones on forest lands where large merchantable trees have been retained to meet riparian rules, while on adjacent agricultural lands it is legal to plow through the stream or have livestock standing in the stream. On residential land, it is legal to cut riparian vegetation and landscape stream banks with any type of structure or vegetation. On urban lands, communities and agencies can line the entire stream channel with concrete and eliminate riparian forests. Land uses on these different types of land clearly are inconsistent and held to different standards. Creation of a general land-use practices act would coordinate management directions and provide more equitable support of society's ecosystem goals. Regulatory requirements on these land-use types would differ because of the range of social expectations, but the various land uses could be evaluated through a common set of ecosystem management questions and related ecological functions. A common commitment to goals for riparian resources would also identify the types of incentives or disincentives that are woven into the current fragmented policy landscape of the Pacific Northwest.

Conclusion

Riparian forests and stream ecosystems in forests of North America have been extensively altered over the last several centuries. One year after the formation of the Bureau of Forestry in 1901, Overton Price (1902) observed that "[i]n effective methods for the harvesting and manufacture of lumber, the American lumberman has no superior, nor is he equaled in his disregard for the future of the forest which he cuts." As we look to the next century, we have the advantage of a few decades of awakening to the need to maintain and restore riparian resources and their ecological functions in forest landscapes. The ecological and social challenges of managing riparian areas in complex landscapes are becoming more acute as human populations grow along with the demand for water, forest products, fisheries, wildlife, and recreational resources.

Resource professionals and the public continually must improve approaches to managing the world's common resources. The success of our efforts will be based not on our static performance at any point in time, but rather on our ability to deal with ecological and institutional change. In *The Influence of Forestry upon the Lumber Industry,* Overton Price (1902) noted that "it is the history of all great industries directed by private interests that the necessity for modification is not seen until the harm has been done and its results are felt." It is this characteristic of human nature and our society that necessitates awareness of historical changes, anticipation of future trends, and development of more effective approaches to maintain and restore riparian forests and aquatic ecosystems.

Literature Cited

Agee, J. K. 1988. Successional dynamics of forest riparian zones. In *Streamside management: Riparian wildlife and forestry interactions,* ed. K. J. Raedeke. Contribution number 59. Seattle, WA: Institute of Forest Resources, University of Washington.

———. 1993. *Fire ecology of Pacific Northwest forests.* Washington, DC: Island Press.

American Almanac. 1994. *American almanac 1993–1994: Statistical abstract of the United States.* 113th ed. Austin, TX: The Reference Press Inc.

Bayley, P. B. 1995. Understanding large river-floodplain ecosystems. *BioScience* 45(3):153–158.

Bisson, P. A., T. P. Quinn, G. H. Reeves, and S. V. Gregory. 1992. Best management practices, cumulative effects, long-term trends in fish abundance in Pacific Northwest river systems. In *Watershed management: Balancing sustainability and environmental change,* ed. R. J. Naiman. New York: Springer-Verlag.

Booth, D. B. 1991. Urbanization and the natural drainage system: Impacts, solutions, and prognoses. *Northwest Environmental Journal* 7:93–118.

Botkin, D., K. Cummins, T. Dunne, H. Regier, M. Sobel, L. Talbot, and L. Simpson. 1995. *Status and future of salmon in western Oregon and northern California: Status and future options.* Report no. 8. Santa Barbara, CA: The Center for the Study of the Environment.

Bottom, D. L., P. J. Howell, and J. D. Rodgers. 1985. *The effects of stream alterations on salmon and trout habitat in Oregon.* Portland, OR: Oregon State Department of Fish and Wildlife.

Boule, M. E., and K. F. Bierly. 1987. History of estuarine wetland development and alteration: What have we wrought? *Northwest Environmental Journal* 3:43–61.

Cummins, K. W. 1974. Structure and function of stream ecosystems. *BioScience* 24:631–641.

Emmingham, W. H., and K. Maas. 1994. Survival and growth of conifers released in alder-dominated coastal riparian zones. *COPE Report* (Oregon State University) 7:13–15.

FEMAT. 1993. *Forest ecosystem management: An ecological, economic, and social assessment.* Report of the Forest Ecosystem Management Assessment Team (FEMAT). 1993-793-071. Washington, DC: GPO.

Frissell, C. A., and R. K. Nawa. 1992. Incidence and causes of physical failure of artificial habitat structures in streams of western Oregon and Washington. *North American Journal of Fisheries Management* 12:182–197.

Gedney, D. R. 1988. *The private timber resource: In assessment of Oregon's forests,* ed. G. J. Lettman and D. H. Stere. Salem, OR: Oregon State University, Department of Forestry..

Gregory, S. V., and L. R. Ashkenas. 1990. *Riparian management guidelines for the Willamette National Forest.* Technical report. Eugene, OR: USDA Forest Service, Willamette National Forest.

Gregory, S. V., G. A. Lamberti, D. C. Erman, K. V. Koski, M. L. Murphy, and J. R. Sedell. 1987. Influence of forest practices on aquatic production. In *Streamside management: Forestry and fishery interactions,* ed. E. O. Salo and T. W. Cundy, 233–255. Contribution no. 57. Seattle, WA: Institute of Forest Resources, University of Washington.

Gregory, S. V., B. Beschta, F. J. Swanson, J. R. Sedell, G. Reeves, and F. Everest. 1990. Abundance of conifers in Oregon's riparian forests. *COPE Report* (Oregon State University) 3:5–6.

Gregory, S. V., F. J. Swanson, W. A. McKee, and K. W. Cummins. 1991. An ecosystem perspective of riparian zones. *BioScience* 41:540–551.

Harmon, M. E., J. F. Franklin, F. J. Swanson, P. Sollins, S. V. Gregory, J. D. Lattin, N. H. Anderson, S. P. Cline, N. G. Aumen, J. R. Sedell, G. W. Lienkaemper, K. Cromack, Jr., and K. W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. *Advances in Ecological Research* 15:133–302.

Hicks, B. J., J. D. Hall, P. A. Bisson, and J. R. Sedell. 1991. Responses of salmonids to habitat change. In *Influences of forest and rangeland management on salmonid fishes and their habitats,* ed. W. R. Meehan. Special publication no. 19. Bethesda, MD: American Fisheries Society.

Iwamoto, R. N., E. O. Salo, M. A. Madej, and R. L. McComas. 1978. *Sediment and water quality: A review of the literature, including a suggested approach for water quality criteria.* EPA 910/9-78-048, U.S. EPA Region X. Seattle, WA: U.S. EPA.

Junk, W. J., P. B. Bayley, and R. E. Sparks. 1989. The flood pulse concept in river-floodplain systems. In *Proceedings of the International Large River Symposium,* ed. D. P. Dodge. Ottawa: Canadian Special Publication of Fisheries and Aquatic Sciences 106, Department of Fisheries and Oceans.

Karr, J., and I. Schlosser, 1977. *Impact of nearstream vegetation and stream morphology on water quality and stream biota.* EPA 600 3-77 097. Washington, DC: U.S. EPA.

Kauffman, J. B. 1988. The status of riparian habitats in Pacific Northwest forests. In *Streamside management: Ri-*

parian wildlife and forestry interactions, ed. K. J. Raedeke. Contribution no. 59. Seattle, WA: Institute of Forest Resources, University of Washington.

Krygier, J. T., and J. D. Hall. 1971. *Forest land uses and stream environment.* Proceedings of a symposium. Corvallis, OR: College of Forestry and Department of Fisheries and Wildlife, Oregon State University.

Lamberti, G. A., S. V. Gregory, L. R. Ashkenas, R. C. Wildman, and K. M. S. Moore. 1991. Stream ecosystem recovery following a catastrophic debris flow. *Canadian Journal of Fisheries and Aquatic Sciences* 48:196–208.

Li, H., C. B. Schreck, C. E. Bond, E. Rexstad. 1987. Factors influencing changes in fish assemblages of Pacific Northwest streams. In *Community and evolutionary ecology of North American stream fishes,* ed. W. J. Matthews and D. C. Heins. Norman, OK: University of Oklahoma Press.

McComb, W. C., K. McGarigal, and R. G. Anthony. 1993. Small mammal and amphibian abundance in streamside and upslope habitats of mature Douglas-fir stands, western Oregon. *Northwest Science* 67:7–15.

McIntosh, B. A., J. R. Sedell, J. E. Smith, R. C. Wissmar, S. E. Clarke, G. H. Reeves, and L. A. Brown. 1993. Management history of eastside ecosystems: Changes in fish habitat over 50 years, 1935 to 1992. In *Eastside forest ecosystem health assessment,* ed. P. F. Hessburg. Volume III, Assessment. Washington, DC: USDA Forest Service.

Meehan, W.R., ed. 1991. *Influences of forest and rangeland management on salmonid fishes and their habitats.* Special publication no. 19. Bethesda, MD: American Fisheries Society.

Moyle, P. B., and R. M. Yoshiyama. 1994. Protection of aquatic biodiversity in California: A five-tiered approach. *Fisheries* 19(2):6–18.

Murphy, M. L. 1995. *Forestry impacts on freshwater habitat of anadromous salmonids in the Pacific Northwest and Alaska: Requirements for protection and restoration.* NOAA's Coastal Ocean Program, decision analysis series no. 1. Washington, DC: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Coastal Ocean Office.

Murphy, M. L., and Koski, K. V. 1989. Input and depletion of woody debris in Alaska streams and implications for streamside management. *North American Journal of Fisheries Management* 9:427–436.

Murphy, M. L., J. Heifetz, S. W. Johnson, K. V. Koski, and J. F. Thedinga. 1986. Effects of clearcut logging with and without buffer strips on juvenile salmonids in Alaskan streams. *Canadian Journal of Fisheries and Aquatic Sciences* 43:1521–1533.

Naiman, R. J., ed. 1992. *Watershed management: Balancing sustainability and environmental change.* New York: Springer-Verlag.

Naiman, R. J., H. Decamps, J. Pastor, and C. A. Johnston. 1988. The potential importance of boundaries to fluvial ecosystems. *Journal of the North American Benthological Society* 7:289–306.

Naiman, R. J., D. G. Lonzarich, T. J. Beechie, and S. C. Ralph. 1991. General principles of classification and the assessment of conservation potential in rivers. In *River conservation and management,* ed. P. J. Boon and G. E. Petts. Chichester, UK: John Wiley & Sons, Inc.

Naiman, R. J., T. J. Beechie, L. E. Benda, D. R. Berg, P. A. Bisson, L. H. MacDonald, M. D. O'Connor, P. L. Olson, and E. A. Steel. 1992. Fundamental elements of ecologically healthy watersheds in the Pacific Northwest Coastal Ecoregion. In *Watershed management: Balancing sustainability and environmental change,* ed. R. J. Naiman. New York: Springer-Verlag.

Naiman, R. J., H. Decamps, and M. Pollock. 1993. The role of riparian corridors in maintaining regional biodiversity. *Ecological Applications* 3:209–212.

National Research Council (NRC). 1992. *Restoration of aquatic ecosystems.* Washington, DC: National Academy Press.

———. 1995. *Upstream: Salmon and society in the Pacific Northwest.* Washington, DC: National Academy Press.

Newbold, J. D., D. C. Erman, and K. B. Roby. 1980. Effects of logging on macroinvertebrates in streams with and without buffer strips. *Canadian Journal of Fisheries and Aquatic Sciences* 37:1076–1085.

Oregon Department of Forestry. 1994. *The Oregon Forest Practices Act: Water protection rules.* Salem, OR: Forest Practices Policy Unit, Oregon Department of Forestry.

PACFISH. 1994. *Environmental assessment for the implementation of interim strategies (PACFISH) for managing anadromous fish-producing watersheds in eastern Oregon and Washington, Idaho, and portions of California.* Washington, DC: USDA Forest Service and USDI Bureau of Land Management.

Pacific Rivers Council. 1993. *Entering the watershed: An action plan to protect and restore America's river ecosystems and biodiversity.* Eugene, OR: Pacific Rivers Council

Peterson, N., A. Hendry, and T. P. Quinn. 1992. *Assessment of cumulative effects on salmonid habitat: Some suggested parameters and target conditions.* TFW-F3-92-001. Olympia, WA: Department of Natural Resources.

Price, O. 1902. The Influence of forestry upon the lumber industry. In *Yearbook of agriculture*. Washington, DC: GPO.

Raedeke, K. J., ed. 1988. *Streamside management: Riparian wildlife and forestry interactions.* Contribution no. 59. Seattle: University of Washington, Institute of Forest Resources.

Reeves, G. E., J. D. Hall, T. D. Roelofs, T. L. Hickman, and C. O. Baker. 1991. Rehabilitating and modifying stream habitats. In *Influences of forest and rangeland management on salmonid fishes and their habitats,* ed. W. R. Meehan. Special report no. 19. Bethesda, MD: American Fisheries Society.

Salo, E. D., and T. W. Cundy, eds. 1987. *Streamside management: Forestry and fishery interactions.* Contribution no. 57. Seattle, WA: Institute of Forest Resources, University of Washington.

Schlosser, I. J., and J. R. Karr. 1981. Water quality in agricultural watersheds: Impact of riparian vegetation during base flow. *Water Resources Bulletin* 17:233–240.

Schoonmaker, P., and A. McKee. 1988. Species composition and diversity during secondary succession of coniferous forests in the western Cascade Mountains of Oregon. *Forest Science* 34:960–979.

Sedell, J. R., and J. L. Froggatt. 1984. Importance of streamside forests to large rivers: The isolation of the Willamette River, Oregon, U.S.A., from its floodplain by snagging and streamside forest removal. *Verhandlungen Internationale Vereinigen Limnologie* 22:1828–1834.

Sedell, J. R., and K. J. Luchessa. 1982. Using the historical record as an aid to salmonid habitat enhancement. In *Symposium on acquisition and utilization of aquatic habitat inventory information,* ed. N. B. Armantrout. Eugene, OR: Western Division, American Fishery Society.

Sedell, J. R., R. J. Steedman, H. A. Regier, and S. V. Gregory. 1991. Restoration of human-impacted land-water ecotones. In *Ecotones: The role of landscape boundaries in the management and restoration of changing environments,* ed. M. M. Holland, P. G. Risser, and R. J. Naiman. New York: Chapman and Hall.

Swanson, F. J., J. F. Franklin, and J. R. Sedell. 1990. Landscape patterns, disturbance, and management in the Pacific Northwest, U.S.A. In *Trends in landscape ecology,* ed. I. S. Zonneveld and R. T. Forman. New York: Springer-Verlag.

Thomas, J. W., M. G. Raphael, R. G. Anthony, E. D. Forsman, A. G. Gunderson, R. S. Holthausen, B. G. Marcot, G. H. Reeves, J. R. Sedell, and D. M. Solis. 1993. *Viability assessments and management considerations for species associated with late-successional and old-growth forests of the Pacific Northwest.* Report of the Scientific Analysis Team. Washington, DC: USDA Forest Service.

Ursitti, V. L. 1991. Riparian vegetation and abundance of woody debris in streams of southwestern Oregon. M.S. thesis, Oregon State University, Corvallis.

USDA and USDI. 1994. *Record of decision for amendments to Forest Service and Bureau of Land Management planning documents within the range of the northern spotted owl: Standards and guidelines for management of habitat for late successional and old-growth forest related species within the range of the northern spotted owl.* Washington, DC: USDA Forest Service and USDI Bureau of Land Management.

Wissmar, R. C., and F. J. Swanson. 1990. Landscape disturbances and lotic ecotones. In *Ecology and management of aquatic-terrestrial ecotones,* ed. R. J. Naiman and H. Decamps. London: Parthenon Press.

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