Sound Watershed Consulting

Creating Functional Water Environments

Scientific Literature Review of Forest Management Effects on Riparian Functions for Anadromous Salmonids

Chapter 1
INTRODUCTION

for

The California State Board of Forestry and Fire Protection

September 2008

2201 Melvin Road, Oakland, CA 94602
(510) 927-2099
www.soundwatershed.com

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1) INTRODUCTION

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For

The California State Board of Forestry and Fire Protection

Prepared by:

Mike Liquori

Dr. Doug Martin

Dr. Robert Coats

Dr. Lee Benda

Dr. David Ganz

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EXECUTIVE SUMMARY

This report summarizes an independent review and synthesis of relevant scientific literature concerning riparian exchange functions to support the California Board of Forestry's deliberations regarding riparian management rules in support of anadromous salmonids in California's state and private forestlands.

This document represents a comprehensive review of 31 scientific literature articles provided by the Board of Forestry to address a series of Key Questions relevant to riparian management for the protection of threatened and impaired watersheds in State and private forestlands in California. The review:

- Summarizes recognized exchange function roles and processes as presented to us by the California Board of Forestry Technical Advisory Committee
- Responds to key questions posed by the Board
- Describes key information gaps not covered within the reviewed literature
- Discusses inferences for forest management from each of the exchange functions

Biotic & Nutrient Exchange Functions

The literature on biotic and nutrient exchange tells us that litter produced in the riparian zone is an important food source for benthic macroinvertebrates , and thus indirectly supports salmonid production. But the quality of litter—its nutrient content and decomposition rate—are as important as the quantity of litter production. Alder produces "fast" (easily decomposed) litter that is rich in nitrogen; maple, willow and cottonwood produce litter of intermediate quality; conifers and oaks produce litter of lower quality and greater resistance to microbial decomposition. The timing of the life cycles of some benthic macroinvertebrates is thought to be synchronized with the production of different litter types.

Alder is not only beneficial to benthic macroinvertebrates, but supports a rich supply of terrestrial insects that fall into a stream from the riparian zone.

Opening the canopy cover over a stream and increasing light intensity has lead in many cases to increased primary (algae growth) and secondary (benthic macroinvertebrate) productivity, which is often beneficial to fish growth and production. In some cases, depending in part on nutrient supply, increased light can shift the dominant algae from diatoms to filamentous green algae, which are less desirable for macroinvertebrates and thus for fish. In opening the canopy over a stream there may be a trade-off between increasing aquatic productivity, which is beneficial to fish, and increasing water temperature, which may be detrimental to fish (see heat chapter)

Small floods increase the supply of food for salmonids by both washing food into the stream, and making flooded areas temporarily accessible for foraging (see water chapter).

A 30 meter wide buffer strip on both sides of a stream (with both equipment exclusion and no tree removal) generally reduces local impacts to a stream that are similar to a “no harvest” level. Completely excluding vegetation management in the buffer strip, however, may forego opportunities to increase fish growth rate and biomass, and to reduce fuel loads.

Topography, geomorphology, regional geography, and associated disturbance regimes strongly influence the vegetative characteristics of riparian zones. The shape and type of these natural landforms may be helpful in guiding buffer configurations including widths and other characteristics (e.g. structure, orientation, density, etc).

The literature suggests that active riparian management could benefit aquatic productivity with silvicultural prescriptions that are designed to enhance temperature regimes, aquatic primary productivity, woody debris recruitment, and reducing fuel loads. These prescriptions could continue to protect streams from known impacts (e.g., erosion from heavy equipment, excessive shade loss), by strategically locating management activities and sizing treated areas to prevent damage yet promote favorable biotic responses. The timing of such riparian management activities could also be scheduled to reduce risk and optimize favorable riparian stand characteristics across a stream network.

Heat Exchange Functions

The literature on riparian heat exchange tells us that shade provided by riparian vegetation is a key factor controlling heat input to streams, even though instream water temperatures are governed by a host of other complex physical factors that control heat transfer between air, water, and the streambed.

There is no single, fixed-width buffer or canopy closure prescription that will provide the desired heat regulation objectives for salmon in all cases. The relative importance of riparian vegetation to influence stream temperature varies by location (geographic province) and by site specific conditions (stream width, depth, flow, groundwater inflow, streambed substrate composition, valley orientation, topographic shading and watershed position). Stream temperature sensitivity to shade is dependent on location and physical conditions.

The science on heat exchange indicates that water temperature protection could be provided by varying the riparian shade requirements in relation to stream temperature sensitivity. This report provides some examples of approaches than can be used, and key variables to consider when designing strategies to manage shade in different settings.

In fish-bearing waters that are directly downstream of headwater streams, the literature indicates that temperature could be positively influenced by providing shaded conditions on headwater stream segments that extend from 500 to 650 ft (150 to 200 m) upstream from the confluence with fish-bearing streams. This distance is based on research findings outside of California, therefore this distance may need to be validated with studies in various California ecoregions.

Our interpretation of the reviewed literature suggests that managing to protect salmonid habitat conditions would require that targets be set for desired stream temperature, and that shade requirements vary in relation to the stream's specific sensitivity to shade as a thermal influence on temperature. The literature indicates that stream temperature is a major factor influencing population performance.

Shade is not static, but varies in response to stand growth dynamics and natural ecosystem processes and disturbances. Suitable thermal conditions could be maintained and hazards to salmonids avoided by altering the timing and spatial position of riparian management activities. Thermal conditions also respond to surrounding conditions as water flows downstream, so downstream stand conditions also influence stream temperature.

Riparian stand effectiveness for shading is a function of the forest canopy density, height, and species composition, which is related to stand type and age. Research shows that effective shading can be provided by buffer widths ranging from 30 to 100 ft (10 m to 30 m) depending on stand type, age, and location.

Timber harvest in or adjacent to riparian areas can influence microclimate, but microclimate changes have not been demonstrated to translate to changes in water temperature.

Timber harvest in or near riparian areas can cause an increase in light penetration, decrease interception of precipitation, and increase wind speed, which can result in higher mid-day air temperatures and lower mid-day humidity near the forest floor and over the stream. These microclimate changes are hypothesized to influence water temperature, however validation is lacking.

Finally, heat exchange is only one riparian function that affects salmonids. Shade conditions can inversely influence biotic and nutrient exchange functions. Similarly, the canopy that provides shade also influences water exchange functions, and can be influenced by wood exchange functions. These dynamics between exchange functions are discussed in greater detail in Chapter 7 (Synthesis).

Water Exchange Functions

The literature on water exchange tells us that forest management activities in riparian areas might affect stream functions, although the effect is likely to be small, highly variable, and strongly influenced by the watershed context.

The predominant effect from management is the loss of riparian canopy, and changes in evapotranspiration associated with tree removal and subsequent regeneration. While there are some lines of logic that might suggest that riparian trees may have greater effects on water runoff processes than upslope trees, there is little direct evidence in the reviewed literature to support such concepts. Hydrologic effects have been studied for entire watersheds; riparian zones alone have not been studied.

Extrapolating to riparian areas suggests that effects from riparian management would likely be small (possibly undetectable) given the variability in runoff response and the ability to measure changes. The literature generally reports that the amount of change in water yield, peak flows and base flow associated with timber harvest is directly related to the amount of tree canopy removed, regardless of where in the watershed those trees are removed.

The effect of reduced canopy interception might be most significant in steep, zero-order basins, where hollows are filled with colluvium and the risk of slope failure can be influenced by levels of saturation. An intact canopy can moderate the intensity of short bursts of rainfall reaching the soil surface, and its removal may thus increase the potential rate of water input to the soil and the likelihood of slope failure. Such processes reflect highly complex soil physics relationships that were not a focus of this literature review.

There is evidence that soil compaction in riparian areas can negatively affect hydrologic processes. Soil compaction can occur when heavy equipment operates on soils at a time when water content in the soils makes them susceptible to compaction.

There is evidence that riparian stand complexity is beneficial for a number of hydrological processes associated with channel development, nutrient exchange, and other functions. Indirect hydrologic effects of riparian management can influence both channel morphology and aquatic ecology in headwater streams. Small increases in peak flow related to timber harvest operations have not generally been thought to adversely affect channel morphology. However, even modest increases in peak flows of the type observed in the literature can be important in some watershed contexts. For example, when such peak flow increases occur in steep channels with erodible substrates, they can potentially increase sediment production from headwater streams. Similarly, increased summer baseflows appear to benefit salmonid habitats by increasing the area of perennial flow in headwater channels.

In recent years, the ecological importance of hyporheic flows is becoming better understood, although the extent that forest management directly benefits or harms this environment is not yet clear. Hyporheic flows describe the flow of water that exchanges between the surface stream and shallow groundwater region immediately surrounding the stream.

There is very little in the reviewed literature that can used to directly address the issue of buffer strip delineation relevant to the water function. The extent of hydrologic saturation in riparian area is highly variable in time and space, and predicting its extent is extremely difficult. There are three dimensions that are important when considering the delineation of hydrologically-influenced riparian zones; lateral, longitudinal and temporal.

There are probably regional differences in the effects of forest management activities or disturbances, although the reviewed literature does not highlight them, since most of the studies are restricted to either Casper Creek (coastal Mendocino County) or other regions outside the state. Regional differences are likely to reflect regional geology, topographic variation, and dominant runoff mechanisms.

Wood Exchange Functions

Forested environments strongly influence salmonid habitat in California through the processes of woody debris entering the stream from riparian areas. This report describes the mechanisms for wood recruitment to the stream environment, the influence of forest management, and factors that affect riparian buffer design.

There are three dominant sources of instream wood; bank erosion, streamside landslides, and treefall from within riparian areas. Each of these sources is influenced by the dominant type, frequency and magnitude of disturbance processes (fire, flood, landsliding, infestation, etc), as well as the rates of competition mortality associated with the existing stand structure. Disturbance, mortality and tree growth in riparian stands are dynamically linked.

In California second-growth forests, approximately 40-60% of observed instream wood comes from bank erosion, approximately 30% comes from streamside landslides, and the remaining amount comes from treefall. These rates vary substantially based on the geographic (e.g. region) and geomorphic (e.g. landscape condition) context for the site.

Once in the stream, wood is subject to transport down the channel network either during floods (fluvial) or debris-flows. Wood that is carried by debris flow only occurs in certain terrains (typically steep, confined headwaters). Wood that is carried by floods is typically shorter than the channel width.

It can be important to understand the existing stand conditions and successional trajectory of the riparian stand because the riparian stand structure strongly influences the qualities of recruited wood and the rate of recruitment. The existing stand structure and successional trajectory also influences the types and qualities of disturbances that can occur at any given site, and disturbances are one of the primary recruitment processes for instream wood.

Forest management can manipulate riparian stand structure in ways that a) affect the growth and mortality dynamics for the stand and b) influence the types, qualities and risks of disturbances. Forest management can also reduce tree recruitment potential and shift the functional inputs from various exchange functions. Management has the potential to improve existing conditions that reflect legacy forest practices. Management can also alter short-term and long-term supply and characteristics of wood. Therefore, management within riparian zones must be conducted carefully, and with clear functional objectives.

Riparian silvicultural objectives that would support ecological functions important to salmonids (and other fauna) should balance competition mortality objectives, growth objectives, and disturbance risks in ways that support exchange function objectives based on a diagnosis of site requirements. Diagnoses may be generalized by the spatial context of the site by considering regional variations as well as watershed-scale variations in the dominant processes that affect stand evolution (i.e. disturbance types). Diagnoses should also consider the expected stand growth and mortality processes based on conditions that influence stand dynamics (e.g. tree species, cohorts, density, size, etc). Together, the major factors that are reported to influence wood recruitment conditions include:

- Existing Stand Density, Composition And Structure
- Stream Type, Order and Watershed Context
- Vegetation Type and Soil/ Site Index
- Regional Context
- Disturbance Context

Riparian management strategies require consideration of both science and policy. The reviewed literature offers many opinions, but little hard data to evaluate the scientific effectiveness of any approach. Ultimately, the choice of the best approach must be guided by forest policy. The ranges of policy alternatives includes:

Riparian Reserves: This approach seeks to maintain large buffer widths to minimize management effects within riparian areas, specifically those indirect management effects on natural rates of disturbance. This approach typically calls for uniform and continuous riparian buffers of up to two site-potential tree heights on fish-bearing streams and one site-potential tree height on non-fish streams. The underlying basis for this strategy is that over long periods of time (typically centuries), late-seral conditions will become re-established in riparian areas, and that such conditions best represent the long-term conditions suitable for salmonids.

Selective Management: This approach seeks to actively design the characteristics of riparian forests (e.g. size, height, species) in a way that influences future wood recruitment potential (e.g. timing of mortality, exposure to disturbance risks) and other functions. Its focus is often to maximize the benefit to riparian functions while preserving the capacity to operate on forest lands to achieve other resource objectives. It achieves this focus by encouraging a stand composition that targets wood recruitment characteristics most suitable to the specific stream environment. This approach recognizes that the total wood volume grown onsite is strongly influenced by stand structure (density, species, age-distributions, etc), and that tree volume and diameter can be manipulated to meet management objectives.

Proactive Enhancement: Another approach described by the reviewed literature is the concept of proactive instream restoration and enhancement in the form of wood placement. The ability to properly design and implement restoration or enhancement projects requires knowledge of hydrology, hydraulics, geomorphology, biology and engineering practices. Instream wood placement is a practice that is continuing to evolve in many land-use settings, and the general perception is that such projects are overall a benefit to salmonids.

There are a wide array of tools and methods available that can objectively inform these management strategies using scientific approaches. There are also several existing information gaps that could improve riparian management.

Sediment Exchange Functions

The literature on sediment exchange tells us that there are a number of different mechanisms associated with forest management that are responsible for producing and delivering sediment to streams. These include surface erosion processes (rills and sheetwash), skid trails, yarding ruts, gullies, soil piping, roads, fire, mass wasting processes (e.g. landslides, earth flows, debris flows, etc.), bank erosion, windthrow and legacy forest management practices.

Associated with these production mechanisms are several mechanisms that contribute to the delivery of sediment to the stream network. Delivery is affected by mass wasting processes and concentrated surface runoff that have the capacity to mobilize sediment on hillslopes. Mass wasting processes can mobilize sediment over long distances, but generally, surface erosion processes only transport sediment short distances in the absence of concentrated runoff pathways.

Riparian buffers are effective at limiting sediment delivery to streams from surface erosion, skid trails, yarding ruts and bank erosion where buffers are employed (primarily on higher-order streams). In the absence of buffers, ground disturbances that are near streams have the potential to deliver sediment, and thus practices that minimize disturbances near the riparian environment are most capable of preventing sediment delivery. Several studies suggest that selective forest management within buffers will not substantially increase sediment production or delivery.

Riparian buffers are only somewhat effective in preventing sediment delivery from gullies, and mostly ineffective at preventing delivery from roads. Other processes like fire, mass wasting and soil piping were not sufficiently addressed by the reviewed literature. Buffers contributed to sediment production and delivery from windthrow in one study in California (Casper Creek in Mendocino County) and several studies in the Pacific Northwest.

The extent that riparian buffers along headwater streams are necessary to prevent sediment deliver is not clear from the reviewed literature. Several studies indicate that Best Management Practices (BMPs) that exclude equipment near streams, minimize soil disturbance, and prevent concentration of runoff in ditches, ruts and gullies should be effective. One study in Washington suggests that such non-buffer BMPs were not be effective, however that study also indicates that these BMPs were either not implemented, or implemented poorly.

There are several factors that complicate the need for buffers in headwaters. Headwaters are dynamic systems where hillslope and channel processes are integrated and linked. Sediment functions in these areas are also dynamically linked with water and wood functions. The concept of disturbance cascades may help to provide an ecologically and geomorphically integrated framework for developing management practices guidelines in these landscapes. Such a framework might benefit by considering practices at larger spatial scales (i.e. sub-watershed to watershed) and longer time scales that recognize the recovery rates associated with various functional processes (see Figure 9).

Source distance relationships for sediment are described in Section 2.2.5. As with other exchange functions, the width for which sediment delivery to streams can be mitigated varies by process and landscape characteristics. The reviewed literature did not provide a sufficient guidance for the various landscape situations in California, although a more detailed analysis of data may lead to more definitive specifications for buffer width.

Road crossing decommissioning studies in California indicate that such practices contribute sizeable volumes of sediment. Such practices reduce the chronic sediment sources from roads, and reduce the risk of road crossing failures that can deliver very large volumes of sediment, and are thus beneficial over the long term. However, there may be opportunities for improvements in road crossing decommissioning practices that could reduce sediment delivery.

Recommended forest management objectives for sediment functions include mitigating harvest-related sediment, mitigating the hydrologic link to sediment delivery, mitigating road sediment, and mitigating for mass wasting impacts. Six specific considerations that would support these objectives are discussed, as well as two concepts for developing spatially-integrated buffer strategies. A summary of buffer dimensions used in regions throughout North America is also provided to help guide policy decisions.

Synthesis

In this chapter, we discuss concepts that will help guide the Board of Forestry toward an integrated approach to riparian management that considers all forms and functions.

We've discovered four key findings throughout our review of the literature that extend across all the exchange functions. These include:

1. Spatial context is important, as it influences functional response patterns.

2. Longitudinal controls (along the channel length) on exchange functions in addition to lateral controls (buffer width) are important in maintaining the watershed-scale ecosystem structure that maintains aquatic habitats.

3. There are dynamic interactions among and between riparian exchange functions that alter the importance of exchange functions for any particular setting.

4. While riparian zones can buffer a stream from direct management impacts, they do not protect streams from disturbances, but in fact alter the disturbance regimes in ways that can affect the functional response expressed by both short-term and long-term evolution of riparian areas.

A shift in thinking from a "protection" mindset (e.g., buffering the stream) to an "ecosystem processes" mindset is consistent with several general themes in the literature in recent years. These papers suggest that it may be a more appropriate management objective to ensure that the ecosystem processes and functions are maintained to provide desired riparian (and instream) conditions in managed settings.

There are three general approaches to achieve this objective that are promoted in the reviewed literature.

Riparian Reserves utilize large buffers so that mature to late-seral stand conditions are eventually achieved.

Resource Optimization seeks to balance appropriate protections against other management objectives.

Advanced Recovery/Enhancement manages growth and disturbance risks to influence ecosystem processes that create conditions favorable to salmonids over the short- and long-term.

The scientific basis for buffer widths is described in terms of source-distance relationships that relate width to the cumulative inputs (or limits) for various functions. The shape of source-distance curves are strongly influenced by the dominant mechanisms or riparian characteristics for contributing (or preventing) the key input associated with each exchange function in that setting. Seven specific limitations in using source distance relationships are described that raise questions regarding the utility and/or effectiveness of using source distance relationships as the sole basis for riparian management.

The scientific basis for longitudinal variation describes regional, watershed, and temporal scales of influence that combine to influence the context for habitat requirements. Managing for longitudinal variation requires an understanding of how different ecosystem processes act to form and maintain habitats throughout the channel network.

The scientific basis for headwater riparian management recognizes that headwaters affect functional responses in downstream reaches. The concept of longitudinal source-distances is offered here as an analog, wherein different characteristic input distances can be measured from the confluence of the headwater tributary junction with fish-bearing reaches. Data to support such source-distance relationships for headwater areas is limited in the reviewed literature.

Riparian forest structure is fundamentally a dynamic expression of growth and disturbance. It is the combination of structural characteristics and disturbance processes that influence functional relationships between riparian areas and salmonid habitats. Management of riparian zones can affect the types of disturbances and vulnerability to disturbances that deliver functional inputs. These disturbances can be beneficial, detrimental, or both.

Our synthesis of the reviewed literature leads us to the conclusion that the importance of maintaining ecosystem functions, including those associated with disturbance, dynamics, growth, and spatial variability, point to the need for an evolutionary step in the design and application of riparian management strategies. A more holistic strategy would integrate landscape-scale concepts into local decision criteria. A wide array of analytical tools for evaluating watershed-scale processes and conditions are available, and the reviewed literature suggests that there is considerable scientific data to inform such tools.

INTRODUCTION

This report summarizes an independent review and synthesis of relevant scientific literature concerning riparian exchange functions to support the California Board of Forestry's deliberations regarding riparian management rules in support of anadromous salmonids in California's state and private forestlands.

The Board has statutory responsibility for a comprehensive set of Forest Practice Rules that govern the planning and conduct of timber operations on private and State-owned timberlands in the State. The Board also has statutory requirements for review of its regulations. Public Resource Code 4553 requires the Board to continuously review and revise regulations to ensure regulatory effectiveness. Specific provisions of the rules are intended to provide protection for anadromous salmonids.

As a consequence of the listing of the Coho salmon as a threatened species under the California Endangered Species Act, the California Department of Fish Game in conjunction with the California Department of Forestry and Fire Protection, landowners and scientific experts, has been directed by the Fish and Game Commission to monitor and review existing timber harvesting regulations for the protection of Coho salmon. This report supports pending deliberations regarding the protection and restoration in watersheds with threatened or impaired values (e.g. 14 CCR §§ 916.9, 936.9, and 956.9).

The Board appointed a 12-member Technical Advisory Committee on Riparian Forests (TAC) to serve as scientific advisors during the literature review and its presentation to the Board. The TAC identified a list of representative scientific literature for review. The TAC compiled 149 articles using several criteria for inclusion in the reviewed literature list. These criteria included a) articles represent recent work (since approximately 1996), b) were conducted with scientific rigor, c) received formal scientific peer review, d) are relevant to processes that are important in California, e) addresses at least one of the exchange functions.

The TAC also developed a set of "Primers" for riparian functions that provided a summary of the accepted concepts associate with 5 key riparian exchange functions associated with water, heat, biotic & nutrients, wood, and sediment. These widely accepted functions are known to affect ecological processes between streams and their adjacent forests. The Primers describe generally accepted concepts as a foundation for the literature review, allowing the review to focus on other important issues.

Project Approach

The Sound Watershed Team provided an independent, objective, non-partisan review of 179 scientific literature articles provided by the Board of Forestry, as well as the 5 "primer" summary articles provided by the TAC. These papers, over 4000 pages of scientific literature, comprise the basis of this review, and are collectively referred to as "reviewed literature". The Team also incorporated our existing understanding of the literature to support various conclusions, and these papers are cited as additional literature.

In reviewing the provided literature, the Sound Watershed Consulting Team focused on topics that have been less well studied, explore unresolved questions or management relationships, and generally inform variations in these functions specific to California forests, streams, and biota. The TAC outlined these unresolved issues through a series of Key Questions that were provided by the TAC.

For each riparian exchange function, Sound Watershed Consulting identified a team of 2-4 people who shared primary responsibility for reviewing the literature and documenting results. Each sub-team worked closely to compile the results for each exchange function. We believe this approach helped to ensure that our review is objective and independent. We selected the sub-team members based on their experience with each riparian exchange function.

The reviewed literature offered some interesting information relevant to riparian science and management. However, we found that many of the papers had limited value in specifically addressing the key questions. In many cases, there simply may not be studies available that address some of the details implied by the key questions.

In several cases, the SWC Team found it somewhat cumbersome to provide responses for the Key Questions. While the key questions appear to have been posed in a manner that maintained objectivity, we often found that the scope and scale of the questions were often quite broad. We could have described considerably more detail than we did, including various exceptions, variations, requirements, and other complexities associated with these functions. However, in the interest of creating a more readable document, we opted for clarity over detail. We refer those interested in more detail to the original literature.

Our responses to the Key Questions sought to outline the predominant trends reported in the reviewed literature. No doubt that in some cases, our responses might have been more completely informed by additional literature. For example, there was very little information available in the reviewed literature related to hillslope hydrology processes that might inform riparian management in headwater streams. Some of these issues may deserve additional consideration.

One convention used in this study is the citation of "others" in reference to various statements throughout this document. We use this convention to indicate that some concepts are discussed by more papers than those specifically cited. A full citation of every relevant paper on these topics would overwhelm both the reader and the authors.

Throughout this review, we were struck by how much data and information is available from the reviewed literature to address specific management practices and prescriptive strategies for the benefit of salmonids. The broad nature of the key questions limited our ability to hone in on many of these details within the scope of this effort. However, we expect that more specific direction regarding the desired policy strategies for addressing these issues will guide those developing prescriptions, and that the reviewed literature can be viewed as a rich resource.

There is a lot more that could be done with this literature in terms of meta-analyses or more detailed literature reviews to inform specific policy objectives or prescriptions. The information and data available from the reviewed literature is rich, and this summary of the literature required often difficult decisions about what not to include. For example, both lateral and longitudinal source-distance relationships could be refined for various exchange functions based on geographic distributions, disturbance risks, or limiting biological factors.

Similarly, criteria for various localized objectives could be established to help identify variations in riparian management that provide improved conditions for salmonids and other species. For example:

- Where disturbance risks might be relevant
- identifying opportunities for increasing stem growth to expedite the conditions where tree diameters are more appropriate to the local stream conditions
- identifying locations where nutrient objectives might be locally more important than wood recruitment objectives
- etc.

Riparian Functions in Support of Salmonid Habitats

It is widely accepted that salmonid habitat can be impacted by forest management. Forested riparian ecosystems influence physical components of streams, including temperature dynamics, water quality and quantity, sediment supply and deposition, food web resources, and instream habitat heterogeneity (CBOF-TAC 2007). Because of these diverse functions, riparian forests help to maintain high-quality instream habitats that are necessary for salmonids and other aquatic species with specialized habitat requirements (Salo and Cundy 1987; others). Thus, regulations governing the management of riparian buffer widths lie at a nexus between environmental, societal, and land development interests, and can yield especially contentious debates among stakeholders.

Government agencies have struggled with how to define and classify small streams and to specify the kinds of protection they should be afforded. As a consequence, there are marked differences in riparian forestry practices and management among jurisdictions throughout North America, and even within the Pacific Northwest, where one should expect some level of congruence given the commonalities in governing conditions (Young 2000; others). Despite the importance of these processes there remains much debate about how specific management actions can either benefit or impact aquatic conditions for salmonids. This study is intended to support policy deliberations through an objective review of relevant literature regarding riparian exchange functions important to salmonids.

The focus of this study was on the dynamics of riparian exchange functions that are important to salmonids. Much of the focus of this study is on the riparian contributions, including details regarding processes and mechanisms that affect the delivery of these functions to the stream environment. This study assumes that these functions are essential to salmonid ecology, and thus does not spend much time exploring the interaction of these functions to salmonids. Instead the focus is on exploring the dynamic interactions between forest practices, the riparian community, and the stream environment. For more information about the biological and ecological instream functions, we refer the reader to Salo and Cundy (1987); Naiman and Bilby (1998); Gregory et al (2003).

BIOTIC AND NUTRIENTS - riparian biotic and nutrient exchange is important to the growth and survival of juvenile salmonids. Key inputs include a) light and nutrients (including dissolved organics), and b) inputs of particulate organic matter and terrestrial invertebrates. These processes are important management considerations necessary to sustain and/or enhance salmonid populations (Bilby and Bisson 1991).

HEAT- There are several reasons to be concerned about increased stream temperatures in the forest environment. Fishery impacts are generally considered to be the most important. Elevated stream temperatures can reduce salmonid juvenile survival rates and lower the abundance and diversity of food organisms for fish (Beschta et al 1987). High water temperatures increase the metabolic rate of fish, increase the number of pathogens attacking them, and decrease the dissolved oxygen content of the water. These problems are most pronounced in the late summer months, when streamflows are very low and there is a large amount of solar energy available to heat the water. Temperature changes which can occur from logging often result in indirect or sublethal effects on fish populations (Holtby 1988). Examples of these types of impacts include the decrease in the emergence time of fry from gravels, and also earlier, less favorable smolt migration to the sea. Other reasons for concern about high stream temperatures exist as well. They include the increase of algae production, reducing the esthetic qualities of the water (Amaranthus 1984).

WATER- The flows of water through a catchment influence a broad range of processes, including soil erosion, biogeochemical cycling, and in-channel sediment transport. Forestry operations such as harvesting and road construction can have a significant impact on hydrology at the site, hillslope, and catchment scales. There is ongoing, vigorous debate surrounding these influences, and they need to be considered in relation to managing forest harvesting in small catchments. In terms of aquatic habitat, the key concerns relate to changes in summer low flows and in peak flows and their effects on channel stability and sediment transport.

WOOD – woody debris in streams and rivers has been recognized as an important component in aquatic ecology, fishery habitat biology, geomorphology, hydrology, and forestry over the past several decades (Gregory et al 2003). Woody debris in streams regulates and stores dissolved and particulate matter and creates temporary reservoirs of coarse sediment, thereby altering local channel gradients and channel morphology (Salo and Cundy 1987; Sullivan et al 1987).

SEDIMENT- the influence of timber harvest on erosion and sediment supply to streams has been a major research topic over the last 40 years, and has contributed to development of forest practice rules designed to mitigate erosion. In California like elsewhere, sediment is delivered to streams by bank erosion, landsliding, and surface erosion following fires or after other ground disturbances, including forestry activities (Benda et al 2005; Hassan et al 2005; Gomi et al 2005).

These are just a few of the ways that riparian forests support salmonid habitat functions. A complete exploration of salmonid ecology is beyond the scope of this paper. Instead, the focus of this report is on the delivery of key exchange functions to the stream environment, and how riparian management can ensure that these functions are supported.

In the following chapters, we explore several key issues associated with the ways that management can affect these exchange functions.

ABOUT THE SOUND WATERSHED CONSULTING TEAM

Sound Watershed Consulting compiled a team of professional scientists with proven experience in forest watershed science and management. The members of this team each have advanced degrees in watershed sciences and have provided technical support to forest management issues in a wide variety of jurisdictions throughout western North America and Southeast Asia. Our team includes:

Mike Liquori, MS, CEG - PROJECT MANAGER

Principal, Sound Watershed Consulting

Mike Liquori has over 14 years of professional experience as a forest watershed geomorphologist and hydrologist with a strong background in watershed ecology and stream corridor restoration. He has extensive knowledge of the management of forest riparian landscapes, and has had responsibilities for directing watershed management on over 860,000 acres of private forestlands in California, Washington and Oregon. He has chaired or participated on several scientific technical committees in support of forest policy objectives. He has applied his multi-disciplinary expertise to resolve management challenges associated with state-wide forest policy (Washington's Forests & Fish Plan), non-industrial private forests (Washington Rural Technology Initiative), watershed management strategies for several large industrial forestland owners, sustainable forestry audits (SFI), habitat conservation plans and restoration projects.

Mike has helped develop a number of forest regulations and guidance documents addressing riparian management, road maintenance and abandonment, forest slope stability, channel migration zones, fish passage, channel typing, forest wetlands, erosion controls, and various Best Management Practices. He has led numerous management projects in watershed analysis, land-use planning, restoration design and scientific research. He has well-developed field interpretation skills which he uses to diagnose and evaluate hydrologic, geomorphic and ecological processes. Mike has taught courses in Forest & Fisheries Interactions, River Ecology and Wildland Hydrology at the University of Washington.

Mr. Liquori contributed to all chapters in this document. He was a primary author for the water, wood, sediment and synthesis chapters, and provided support to the Heat and Biotic & Nutrient chapters. He also provided senior editorial review for the entire document.

Doug Martin, PhD

Principal, Martin Environmental

Dr. Martin is a fisheries biologist with extensive multi-disciplinary experience in forest management all along the Pacific region. He has been an active co-chair of the Washington State Forest Practice Board's Cooperative Monitoring, Evaluation & Research Committee since 2000, where he has lead state-wide adaptive management programs addressing the impacts of forestry on clean water and salmonid habitats. Dr. Martin was a key scientific advisor to the Washington State Forest & Fish Plan. He has been a principal investigator for several long-term research programs in Alaska and Washington State addressing the use and application of riparian buffers in forestry. Dr. Martin's extensive knowledge of the literature, along with his unique experience across each of the Riparian Exchange Function disciplines makes him a key asset for this project. Dr. Martin's primary contributions were to the Biotic and Nutrient, Heat and Synthesis chapters.

Bob Coats, PhD,

Principal, Hydroikos & Adjunct Research Professor, UC Davis

Dr. Coats has 35 years of experience focusing on the hydrologic and ecological effects of land management on aquatic ecosystems. This work has concentrated in two areas: wetlands and forested watersheds. In both areas, he has drawn on his background in hydrology, ecology, and soil science. His long-term research interests are focused on nitrogen cycling and biogeochemistry at the watershed level.

In the area of forested watersheds, his experience includes research on the effects of land disturbance on water quality; evaluation of the effects of silvicultural activities on both site quality and water quality; review of proposed timber harvest plans and National Forest plans; reclamation and hydrologic aspects of strip mining in arid lands; evaluating the hydrologic and water quality effects of hydropower projects; and developing monitoring programs and habitat conservation strategies for two Habitat Conservation Plans (pursuant to the Endangered Species Act) in north coastal California.

Dr. Coats primary contributions included the Biotic and Nutrient, Water, Heat, and Synthesis chapters.

Lee Benda, PhD

Principal, Lee Benda & Associates

Lee is a world-renowned geomorphologist with extensive knowledge of the forest landscape in California and the Pacific Northwest. In addition to analyzing effects of human land uses on environments, Dr. Benda also endeavors to place human disturbance within the context of natural disturbance, including storms, fires, and floods. This approach has led to a series of contributions in the watershed sciences with implications for resource management, conservation, regulation, and restoration. Benda has been a leader in the development of interdisciplinary analytical tools, like NetMap, that can be used to investigate the naturally dynamic behavior of watersheds and human's interaction within it. Dr. Benda has also pioneered the development of watershed analysis methods and has extensively studied the interaction of wood, sediment and streams. His primary contributions include the Wood and Sediment chapters.

David Ganz, PhD,

David Ganz currently leads the work of the 19-person Global Fire Initiative, for The Nature Conservancy which is focused on abating fire-related threats to biodiversity around the world. David is an expert in fire science, policy and management who also has experience integrating fire with some new and emerging conservation opportunities like sustainable livelihoods, climate change adaptation, ecosystem services, biofuels, avoided deforestation and community forestry.

He has worked for United Nations' FAO at the Regional Community Forestry Center in Bangkok, Thailand, managing a variety of projects focused on Southwestern China and Southeast Asia. More recently, he was a senior scientist in charge of forestry and fire science projects for TSS Consultants and vice president of international operations for the Renewable Energy Institute. Recent projects have included organizing and facilitating both the China E5 Biofuels Assessment and the Pinchot Institute's independent science review of the Quincy Library Group pilot project.

Dr. Ganz's doctoral research in the Sierra Nevada evaluated the forest health and management implications of various prescribed burning and thinning treatments. More recently he has focused on facilitating processes in which local communities have substantial involvement in deciding the objectives and practices involved in preventing, controlling or utilizing fires. He has published more than 30 papers in technical journals with a primary focus in the fields of fire science, forest health, silviculture and community forestry.

Dr. Ganz provided support to the Wood, Sediment and Synthesis chapters.

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