How Much Dead Wood in Stream Channels Is Enough?[1]

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Abstract
Private forest managers often seek guidelines on how much dead wood should be retained in streams in order to adequately fulfill ecosystem functions. There are three approaches to answering this question for a particular reach of channel. The first approach uses an understanding of *ecologic functions* of dead wood in streams to determine the amount needed to fulfill ecologic and geomorphic functions. This approach fails because the complexities of sizes, shapes, and arrangements of dead wood in a variety of lotic ecosystems overwhelm any scientific specification of target loadings. Another approach uses *reference loadings* to evaluate departures in amounts of dead wood in streams from reference amounts in unaltered systems. A precise threshold cannot be defined using this approach because dead wood volumes are highly variable, even within pristine channels in similar settings, and distributions for managed and pristine channels overlap. A third approach constructs a *wood budget* by evaluating past, present, and projected supplies in streams and riparian areas. This is a cumulative-effects analysis that shifts the focus from channels to riparian forests. In combination, the three approaches provide the best information to determine how much wood is enough, but they do not offer simple, formulaic prescriptions. The demands for performing the necessary analyses before harvesting riparian wood suggest that management of riparian forests will continue to be guided most often by general prescriptions.

Introduction
A primary goal of managing riparian forests is to maintain sufficient dead wood in stream channels so that it fully performs its natural geomorphic and ecologic functions. Much is at stake in balancing the economic and ecologic values of riparian wood. Today, most land managers appreciate the value of dead wood in large fish-bearing channels, although less is known or appreciated about its value in low-order, intermittent tributaries. This gap is critical because first- and second-order channels comprise a large portion of the drainage network; in sixth-order drainage networks, for example, such low-order channels account for roughly two-thirds of the total channel length. The economic value of riparian wood can be evaluated from the market, although the profit realized by a timberland owner is uncertain, due in part to evolving regulations. The ecological value cannot be evaluated as precisely because of the complexity and variability of riparian conditions and processes supporting the functions of dead wood in aquatic ecosystems. How do we weigh the economic and ecologic contribution of riparian wood and manage riparian forests under some inevitable uncertainties?

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In the 1994 Northwest Forest Plan (FEMAT 1993), Federal agencies managing forests in the Pacific Northwest pled ignorance of natural processes and gave guidelines for setting aside riparian reserves in which direct pathways of watershed products (water, sediment, wood, heat, and nutrients) to aquatic ecosystems would not be disturbed by human activities until those pathways were analyzed and understood (e.g., watershed analysis; FEMAT 1993). Although the implementation of these guidelines remains controversial, this strategy greatly simplifies management decisions in riparian reserves once they are designated. In contrast, many private forest owners press to limit the size of buffer strips and continue entering riparian forests to harvest timber. Extracting riparian wood without significantly impacting lotic ecosystems requires more active management strategies and motivates better understanding of the dynamics and functions of dead wood and other functions of riparian forests for aquatic ecosystems. The private forester might phrase the problem as: "How much wood should I retain in order to satisfy the ecologic functions that society demands?"

This question can be analyzed by using three approaches:

1. *Ecologic functions*: Determine the amount of dead wood in streams needed to fulfill vital functions, e.g., maintaining habitat for a sensitive species.
2. *Reference loadings*: Determine desired amounts of dead wood in streams from amounts in unaltered systems.
3. *Wood budgets*: Determine desired amounts in streams and riparian sources by constructing a wood budget to evaluate past, present, and projected supplies.

In this paper, I evaluate these approaches and present a new compilation of data on dead wood volumes in California and Oregon.

Approach 1: Ecological Functions of Dead Wood

The great variety of functions of dead wood in lotic ecosystems is summarized elsewhere (Harmon and others 1986, Sedell and others 1988), and I will mention only a few here for the sake of discussion. In general, lotic communities have evolved with natural and variable supplies of watershed products, including large quantities of wood in forested streams. Dead wood is commonly the most important source of structure in forest streams. It also affects the routing of other watershed products, particularly sediment, and their influence on ecosystems. By concentrating and dispersing hydraulic forces, dead wood can greatly diversify physical conditions in streams and provide habitats for various species and age classes in aquatic communities.

A salient characteristic of dead wood in channels is its variability in terms of supply, longevity, and function. The diameter of dead wood is commonly larger than bed particles by an order of magnitude or more and comparable in scale to channel depth; wood length is comparable to channel width. Thus, single pieces can locally control channel morphology. Consequently, the myriad of sizes and shapes of dead wood can create a myriad of channel forms at the reach scale, depending on the arrangement of the wood and the background geomorphic and hydrologic conditions of the channel. One must be careful not to discount the variety of functions of dead wood in aquatic and riparian ecosystems. Nevertheless, the population of dead wood as distributed naturally in channels is highly inefficient in performing some easily recognizable functions for habitat. On the one hand, a single piece can strategically lodge along a channel thalweg at the outside bank of an incipient bend and thereby scour a deep pool. But more wood is likely to hang up on a bar or flood plain and interact with the flow only during flood stages. Thus, the influence of a single piece can vary widely as it moves downstream.

Moreover, dead wood in channels tends to be concentrated. Common wood input processes—wind storms, wildfire, landslides, and debris flows—quickly deliver large amounts of wood at points in the channel network. Even if inputs are widespread, fluvially transported wood tends to aggregate (Braudrick and others 1997). Although deposited aggregates (debris jams) can strongly affect channels, the obvious influence of individual pieces diminishes quickly with growth of the aggregate.

I do not mean to imply that there is plenty of wood to spare in streams, but that it is impossible to practically and scientifically specify how much is enough. The diversity of size and arrangement of wood and the diversity of channels makes it futile to say how a given amount of dead wood will result in particular habitat conditions. Effects are complex and stochastic. On the one hand, channels without dead wood or other forms of structure can quickly evolve to very simple forms. Moderately sized channels with gradients of about 1 to 4 percent are particularly prone to simplify, because they have a weak tendency to form bars and pools without exogenous structure (Montgomery and Buffington 1997). These conditions typify fish-bearing streams in managed forests in the west. On the other hand, the typically large volumes of dead wood in pristine forest channels contribute to diverse habitats. There is no scientifically defensible, site-specific way to determine what smaller amounts would adequately perform the same functions. For channels in intensively managed private forests, where is the middle ground? This type of uncertainty was the motive in the Northwest Forest Plan for setting aside riparian reserves with strong limitations on entry.

By using approach 1 alone, we are presently incapable of resolving the issue of how much wood is enough. Approach 1 motivates further research and conscientious, site-specific management of streams. By exploring the functions of dead wood in aquatic ecosystems, it provides a scientific basis for managing forest streams. However, it offers no simple prescriptions for the broader, regulatory arena.

Approach 2: Reference Values of Dead Wood Loading

Another approach to determining how much dead wood is enough is to compare volumes and sizes in a given channel to those in comparable channels that serve as references. Given that aquatic communities evolved long before intensive forest- and waterway management began, pristine channels offer the obvious reference condition. Management within the range of pristine conditions provides a level of confidence that natural communities will persist. Although this reference may not always be attainable under management, it provides a standard to measure departures from natural conditions. To apply this approach, we need to know how the volume and size of dead wood varies between regions and within a region, and how management affects those variations.

Let us consider dead wood volumes first. I compiled frequency distributions of in-channel volumes of dead wood (m^3 per ha of bankfull channel area) in unmanaged forests in different climatic regions of California and Oregon *(fig. 1).* Distributions in each region were compiled from a small sample of 9 to 12 reaches that were at least 200 m in length. The channels are second- to fourth-order; drainage areas range from 50 to 3,000 ha. Because these reaches were not selected randomly, they do not represent an unbiased sample of pristine conditions. Despite these limitations, the data show some expected trends. There are wide differences between regions. For example, the median loading for old-growth redwood is about 1,000 m^3/ha, while median loading for mixed conifers in the northern Sierra Nevada is only 30 m^3/ha. This indicates that reference (or pristine) loadings for one region must not be applied to another. There are also wide variations within regions; the difference between minimum and maximum loadings is well over tenfold in each region.

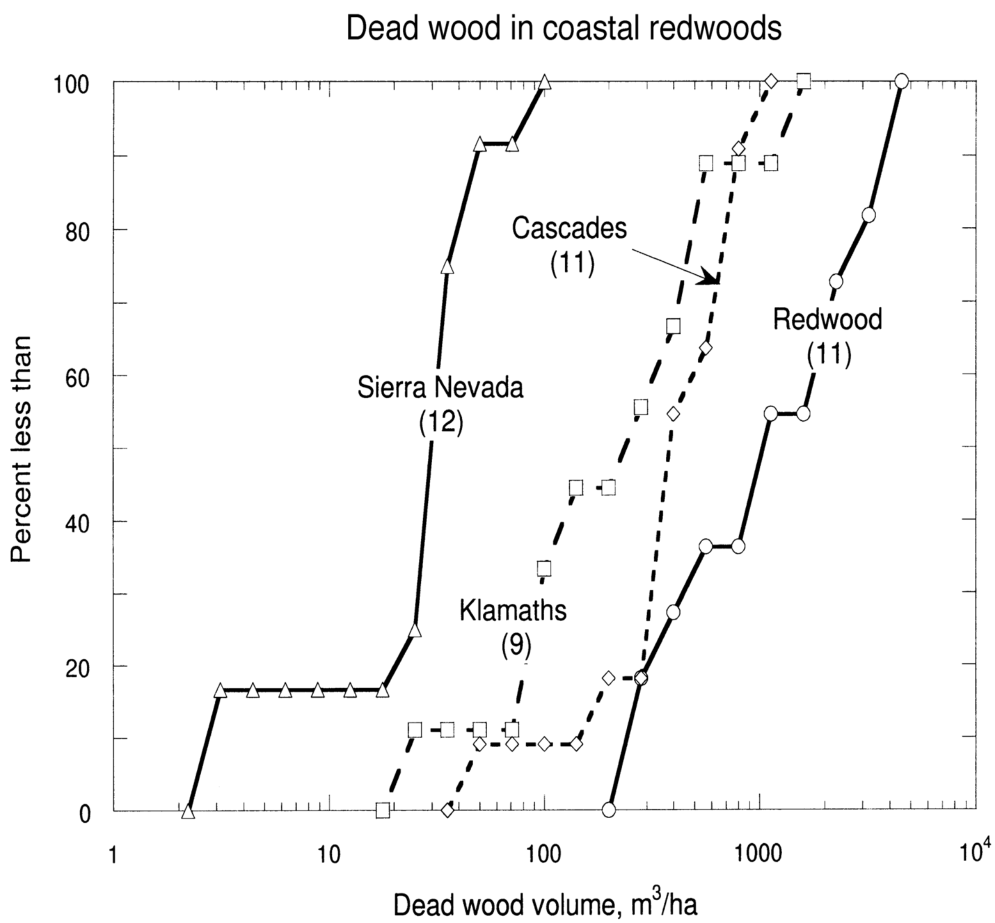

Figure 1—Cumulative frequency distributions of volumes of dead wood in pristine channels in four forest types: Oregon Cascades and Klamath Mountains (Harmon and others 1986); coastal redwood (Keller and Tally 1979); and Sierra Nevada (Berg and others 1998). Number of channels in the sample are given in parentheses. Study reaches are at least 200 m long.

Within coastal redwood forests, management has clearly reduced dead wood volumes in streams. Channels flowing through managed redwood forests contain two to five times less wood than old-growth channels for a given cumulative percentage *(fig. 2)*. A history of logging, log running, salvage, and stream cleaning has apparently created a deficit of wood in channels. However, as is common with environmental parameters, distributions for managed and unmanaged channels overlap. Although there is a clear departure of managed channels from pristine conditions, a comparison of frequency distributions is not very useful for prescribing target loadings for individual channels. For example, using a "natural-range-of-variability" criterion could suggest that loadings of 200 m^3/ha in managed channels would meet "natural" conditions since such low loadings are represented in at least one old-growth channel. However, such a prescription would tend to increase the wood deficit on a regional scale, because improvement would be prescribed only for the 20 percent of managed channels having the lowest loading. On the other hand, a prescription of the median old-growth loading (1,000 m^3/ha) might substantially decrease the regional deficit, but would be unachievable in most managed channels since one-half of the old-growth channels (nearly all in reserves) would already be "in violation." A single-valued prescription for woody debris loading, even in the same forest type, is therefore unworkable.

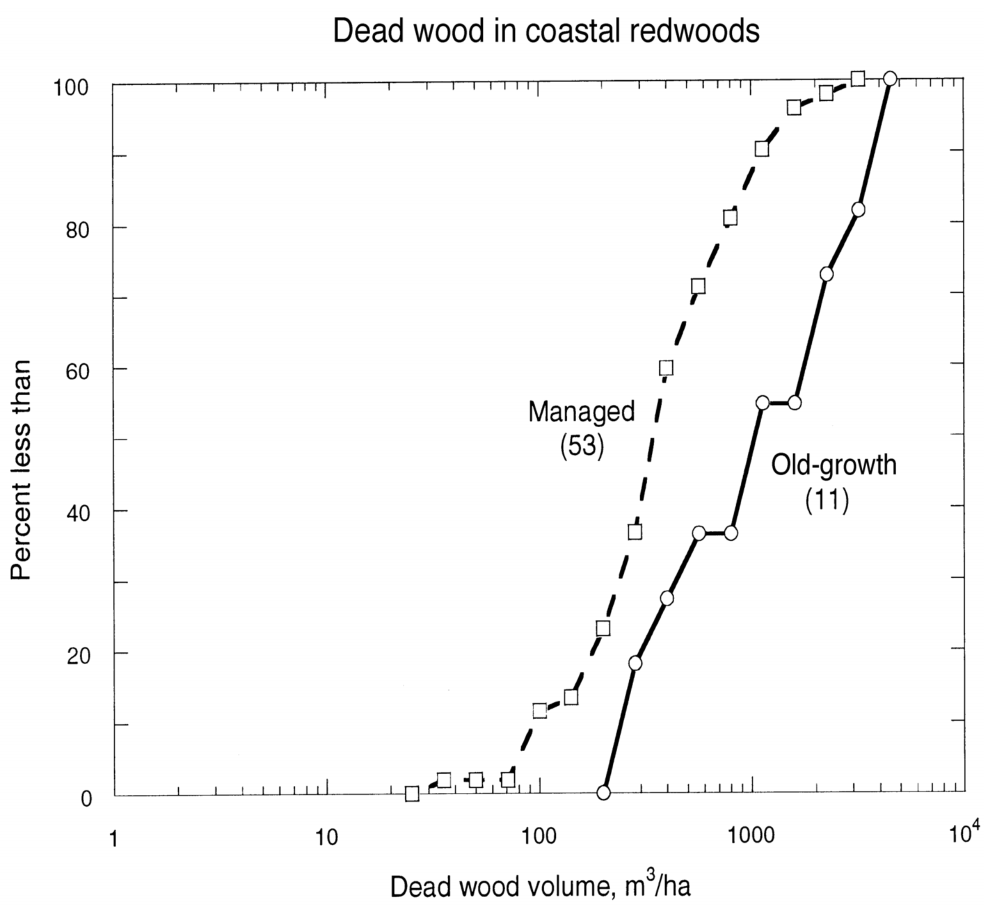

Figure 2—Cumulative frequency distributions of volumes of dead wood in channels in managed (Knopp 1993) and old-growth (Keller and Tally 1979) coastal redwoods. Number of channels in the sample are given in parentheses. Study reaches are at least 200 m long.

Differences in wood size between pristine and managed streams are probably also pronounced. As large, old-growth dead wood in managed streams decreases through decay, salvage, cleaning, and mobilization, it is replaced by smaller wood from managed stands. The size difference is important because big wood lasts longer and affects channels more strongly. The difference is exemplified in a comparison of frequency distributions of the volume of individual pieces of dead wood in two third-order, coastal redwood channels having similar drainage areas: Little Lost Man Creek (Keller and Tally 1979), an old-growth channel, and North Fork Caspar Creek, a second-growth channel *(fig. 3)*. Old-growth wood in Caspar Creek was nearly eliminated by splash-dam operations at the turn of the century, and second-growth forests have since supplied wood without human intervention (Napolitano 1998). For this analysis, the lower bound of piece size was set at 0.4 m^3. The frequency of small sizes (0.4-0.8 m^3) is similar, but frequencies diverge rapidly for larger sizes. The second-growth channel clearly has smaller wood.

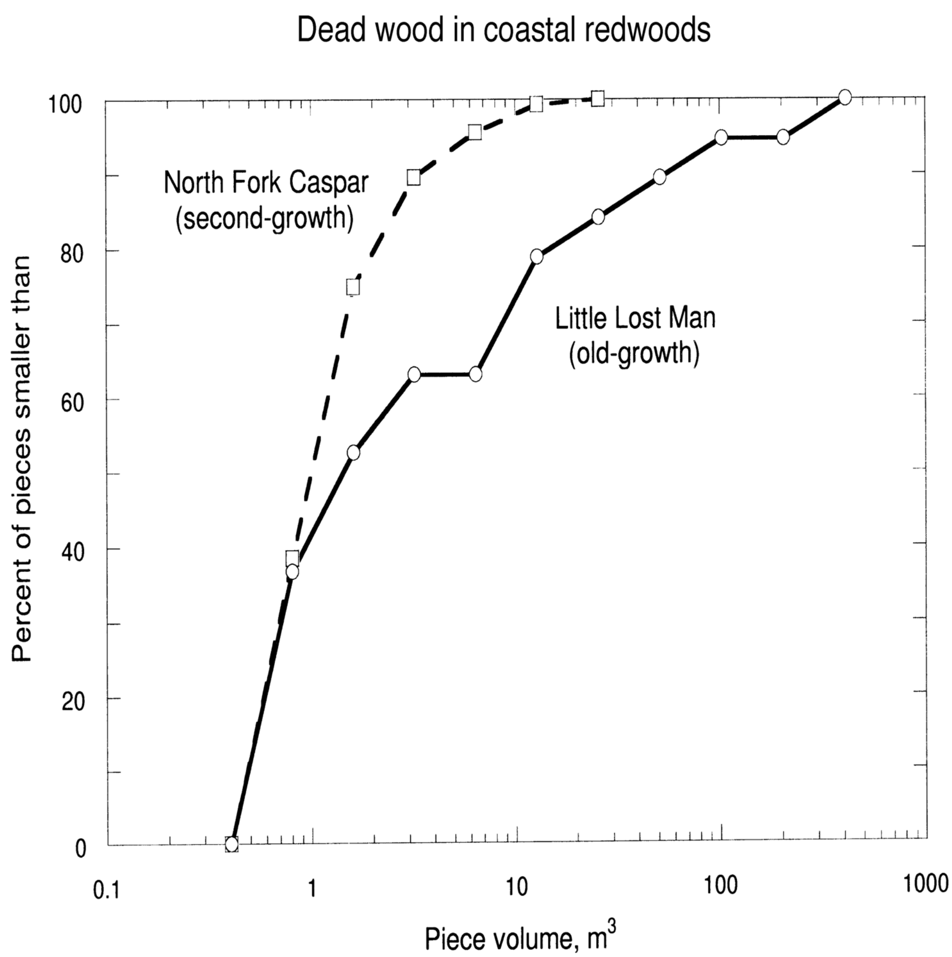

Figure 3—Cumulative frequency distributions of volumes of individual pieces of dead wood in two coastal redwood streams: North Fork Caspar Creek (second-growth) and Little Lost Man Creek (old-growth; Keller and Tally 1979).

Although approach 2 fails to prescribe uniform target loadings (and sizes), some general goals and directions for regional management for dead wood in aquatic ecosystems are clearly suggested. First, there is an apparent regional deficit in dead wood loadings that is probably affecting species such as coho salmon that benefit from wood-formed habitats. This could motivate regional goals to improve protection of in-channel and riparian supplies of wood. Second, the wide variation and overlap between wood loadings in managed and pristine streams suggest that site-specific analyses are needed to achieve these goals if riparian wood is to be harvested.

Approach 3: Dead Wood Budgets

One of the shortcomings of approaches 1 and 2 is that even if we knew how much wood in streams is enough, we would also have to know how to manage riparian forests to achieve that loading. Approach 3 widens the focus to wood supplies in riparian forests. Wood in streams is evaluated in context of the potential of the riparian forest to furnish adequate wood to the channel, given historical inputs and outputs that have culminated in the present loading. Then, current and projected trends can be evaluated under alternative management. By accounting for local variations in wood loading, approach 3 is the site-specific alternative to approach 2. Implicit in the analysis is the consideration of size as well as volume of wood. Approach 3 is essentially a cumulative effects analysis accomplished by constructing a wood budget (Surfleet and Ziemer 1996, Swanson and others 1982) to answer three questions:

- What accounts for present wood loading, and more specifically, how much has land use affected riparian sources and input and output mechanisms since intensive land use began?
- What is the trend in wood loading given the present and future potential of the existing riparian forest to contribute wood to the stream?
- How will management alternatives affect future loadings?

Although historic values for volumes of wood lost or gained usually cannot be determined precisely, enough can be learned of past events and conditions to roughly evaluate departures from natural loadings. This may be adequate to inform managers which alternative land use plans would be appropriate, given present and projected trends in wood supplies. For example, if there has been a history of wood depletion from log runs in the nineteenth century in a particular stream, followed by aggressive stream cleaning in the 1980s, then there would be added incentive to maintain recovering supplies in managed riparian stands. Wind throw from narrow buffer strips might provide short-term increases in wood, but early cashing-in of remaining wood supplies could perpetuate the deficit in future decades.

Wood size as well as volume must be considered in a wood budget. Sustainable supplies of old-growth wood are gone from most managed streams. In its absence, the effectiveness of smaller size classes of available wood to replace the functions of old-growth wood needs to be evaluated (approach 1). Perhaps some minimum effective size can be used to categorize size classes in a wood budget. Longevity is another important consideration.

A wood budget (approach 3), along with knowledge of the role of wood in that particular channel (approach 1) and its loading compared to that in other channels in the same forest type (approach 2), provide the best information to weigh land use alternatives. It correctly sets the stage for regulatory debate by shifting the focus on how much wood is enough from channels to the riparian zone. However, it does not provide a standard formula for making such a determination, but instead informs the debate.

Conclusions

Dead wood in streams in the Pacific Northwest is being managed in the context of conflicting interests of protecting sensitive salmonid populations and tapping riparian wood supplies for timber. This motivates the question: "How much dead wood in forest streams is enough?" Federal agencies in the Northwest Forest Plan effectively skirted this question in favor of salmonids by designating riparian reserves that, among other provisions, were intended to fully protect riparian supplies of dead wood for streams. The Federal provisions, applied over a wide area to important protected species, set an undeniable precedent. If not met on State and private land, an alternative strategy is needed: If habitat is to be adequately protected as riparian wood is harvested, then detailed, site-by-site analyses of dead wood and other habitat variables must be performed. I suggest that three kinds of information are needed for such analyses: the role of dead wood in forest streams and watersheds; relative volumes and sizes of dead wood in managed and reference streams in the same forest type; historical and projected conditions, events, and processes that control wood supply and longevity in riparian forests and streams. Together, they provide the best information to guide land-management decisions. However, analyses must be site-specific. Simple, effective, standardized prescriptions, formulas, or procedures requiring little understanding are not obviously forthcoming.

One cost of intensive management of riparian forests is to support site-specific analyses that could justify harvesting riparian wood. Adequate wood-based, cumulative effects analyses are unlikely to be done because first, such analyses would be costly and their conclusions contestable under the inevitable uncertainties outlined in this paper; and second, considering the widespread depletion of dead wood from streams in managed forests, these analyses are not likely to support harvesting much wood from riparian forests. Given this, general prescriptions of riparian preserves are likely to remain the primary approach to managing dead wood in streams. In the meantime, continued research into the three approaches should better inform general prescriptions and improve site-specific analyses. In particular, approach 1 provides the scientific basis for determining how much wood is enough; approach 3 leads to how this can be achieved.

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References

Berg, N.; Carlson, A.; Azuma, D. 1998. **Function and dynamics of woody debris in stream reaches in the central Sierra Nevada, California.** Canadian Journal Fisheries and Aquatic Science 55: 1807-1820.

Braudrick, C. A.; Grant, G. E.; Ishikawa, Y.; Ikeda, H. 1997. **Dynamics of wood transport in streams: A flume experiment**. Earth Surface Processes and Landforms 22: 669-683.

Forest Ecosystem Management Assessment Team (FEMAT). 1993. **Forest ecosystem management: An ecological, economic, and social assessment**. Washington, DC: U.S. Government Printing Office.

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

Keller, E. A.; Tally, T. 1979. **Effects of large organic debris on channel form and fluvial processes in the coastal redwood environment**. In: Williams, G. P.; Rhodes, D. D., editors. Adjustments of the fluvial system. Binghamton, NY: Kendall/Hall; 169-197.

Knopp, C. 1993. **Testing indices of cold water fish habitat.** Santa Rosa, CA: North Coast Regional Water Quality Control Board; 56 p.

Montgomery, D. R.; Buffington, J. M. 1997. **Channel-reach morphology in mountain drainage basins.** GSA Bulletin 109(5): 596-611.

Napolitano, M. B. 1998. **Persistence of historical logging impacts on channel form in mainstem North Fork Caspar Creek**. In: Ziemer, R. R., editor. Conference on coastal watersheds: The Caspar Creek Story. Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 97-102.

Sedell, J. R.; Bisson, P. A.; Swanson, F. J.; Gregory, S. V. 1988. **What we know about large trees that fall into streams and rivers**. In: Maser, C.; Tarrant, R. F.; Trappe, J. M.; Franklin, J. F., editors. From the forest to the sea: A story of fallen trees. Gen. Tech. Rep. PNW-GTR-229. Portland: OR. USDA Forest Service; 47-81.

Surfleet, C. G.; Ziemer, R. R. 1996. **Effects of forest harvesting on large organic debris in coastal streams**. In: LeBlanc, J., editor. Coast redwood forest ecology and management; Arcata, CA: Humboldt State University; 134-136.

Swanson, F. J.; Fredriksen, R. L.; McCorison, F. M. 1982. **Material transfer in a western Oregon forested watershed**. In: Edmonds, R. L., editor. Analysis of coniferous forest ecosystems in the western United States. Stroudsburg, PA: Hutchinson Ross Publishing Company; 233-266.