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STREAMS IN THE COASTAL REDWOOD ENVIRONMENT: THE ROLE OF LARGE ORGANIC DEBRIS

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ABSTRACT

Large organic debris (greater than 10 cm in diameter) has a major control on channel form and process (and thus anadromous fish habitat) in streams of the coastal redwood environment. Several lines of evidence support this conclusion: first, large organic debris may reside in the stream channel for centuries and, therefore, is a permanent part of the fluvial system; second, large organic debris exerts considerable control over channel morphology, particularly in the development of pools; third, large organic debris produces numerous sediment storage sites, supporting a sediment buffer system that modulates the routing of sediment through the fluvial system; and fourth, large organic debris in steep streams significantly effects the way potential energy is expended by concentrating energy expenditure over short reaches where organic steps or other accumulations of debris exist.

Large organic debris in streams is pertinent to two interrelated management problems in northwestern California: restoration and enhancement of anadromous fish habitat, and reduction of sediment pollution. Management of streams to maximize production of anadromous fish in the coastal redwood environment should consider the entire fluvial system, including the role of large organic debris. Large organic debris in unusually large amounts may block fish migration and cause adverse channel erosion. However, within limits, large organic debris is probably necessary for many streams sustaining anadromous fisheries. Therefore, stream clearing operations must carefully weigh the benefits of locally stabilizing stream banks, opening up stream anadromous fish habitat, or marketing merchantable timber with potential dangers in losing hydrologic variability and mobilizing large quantities of sediment stored in conjunction with large organic debris.

INTRODUCTION

The purpose of this paper is to, first, discuss the role of large organic debris (logs, stems, limbs and rootwads greater than 10 cm. in diameter) in the formation and maintenance of anadromous fish habitat and, second, discuss implications for stream management.

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Large organic debris in the active stream channel has a major control on channel form and process and thus anadromous fish habitat in streams of the coastal redwood environment. Large organic debris resides in the channel for centuries, facilitating the storage of considerable bed load while providing a natural buffer that modulates the routing of sediment, influencing the development of pools, riffles and channel bars, and locally concentrating much of the drop in channel elevation at organic steps or other accumulations of large organic debris. Thus, debris is pertinent to the solution of two interrelated management issues in northwestern California: restoration or enhancement of anadromous fish habitat, and sediment pollution associated with timber harvesting or other land use changes that adversely effect fish habitat.

The decline in recent years of anadromous fish along the north coast is well documented; many rivers and streams that once supported relatively large fish runs of salmon and steelhead trout now have significantly smaller runs (Denton, 1974). Causes for the decline in numbers of anadromous fish are multiple and complex, but most likely are related to human use of hillslopes adjacent to stream channels rather than natural processes, such as floods, or human activity not related to the stream environment, such as overfishing in the ocean.

A generalized life cycle for anadromous fish is shown on Figure 1. Two stream environments are emphasized: pools and riffles. Pools and riffles are formed and maintained by a complex scour-fill sequence related to the morphology of the stream and the interactions between flowing water and moving sediment (Keller, 1972; Keller and Melhorn, 1973 and 1978). Pools are topographic low areas in streams produced by scour during relatively high channel-forming flows that occur every year or so. Riffles are topographic high areas in streams produced by deposition during relatively high channel forming flows. In gravel-bed streams, only the relatively fine sediment may be transported at low flow; the general pattern is for the finer sediment to be transported from riffles into pools.

In many gravel-bed streams that have not been impacted by human use, there is very little fine sediment and so pools are areas of deep slow-moving water during the summer low flow times, providing rearing habitat for juvenile anadromous fish. Land use changes such as timber harvesting and road building that causes an increase in sediment production (particularly fine sediment) may adversely affect pool environments during the summer low flow period by infilling of pools with resulting degradation to the nursery areas for those anadromous fish such as silver salmon and steelhead trout that must remain in the stream for a year or so before migrating to the ocean. An important limiting factor to fish production is, therefore, the pool environment during the summer (low flow) months. In addition, fine sediments fill the interstices of spawning gravels. This prevents aeration necessary to sustain fish eggs and poses a barrier to emerging fry.

The data base upon which inferences concerning the role of large organic debris on stream channel form and process as well as anadromous fish habitat is shown on Table 1. Three of the watersheds, Hayes, Creek, Little Lost Man Creek, and Prairie Creek, are classified as undisturbed because the basins are vegetated with old growth redwood and associated flora. The Casper Creek watershed was logged approximately 80 years ago and now supports an advanced

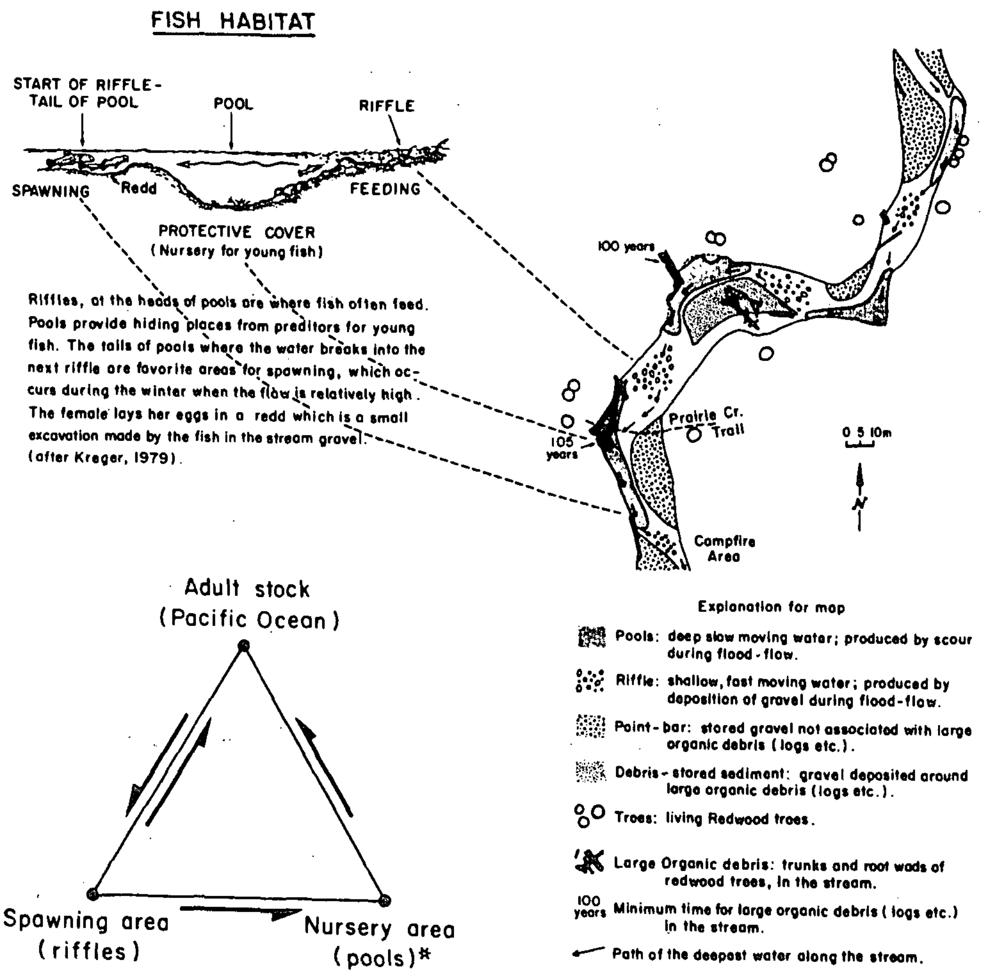

Figure 1. Keller, MacDonald & Talley

Table 1. Comparison of Morphologic Data for Disturbed and Undisturbed Watersheds, Northwestern California [(a)]

Study Reach	Disturbed: Casper Cr. Upper	Disturbed: Casper Cr. Lower	Disturbed: Lost Man Cr.	Disturbed: Larry Damm Cr.	Disturbed: Hayes Cr.	Undisturbed: Little Lost Man Cr. Upper	Undisturbed: Little Lost Man Cr. Lower	Undisturbed: Prairie Cr. Hope Cr. Reach	Undisturbed: Prairie Cr. Little Cr. Reach	Undisturbed: Prairie Cr. Forked Cr. Reach	Undisturbed: Prairie Cr. Zig Zag No. 2	Undisturbed: Prairie Cr. Natural Tunnel	Undisturbed: Prairie Cr. Brown Cr.	Undisturbed: Prairie Cr. Campground
Upstream basin area (km^2)	1.6	3.9	1.1	3.7	1.5	3.5	9.1	0.7	3.5	6.6	8.2	11.2	16.7	27.2
Stream order	2	2	2	3	2	2	2	2	2	2	2	2	3	4
Slope	.016	.013	.048	.014	.12	.033	.048	.02	.014	.012	.009	.01	.01	.005
Debris loading (kg/m^2)	21.0	24.0	105.0	76.0	170.0	141.6	49.0	218.0	12.3	13.1	21.7	106	84.8	19.6
Pool to pool spacing (in channel widths)	3.5 (b)	3.8	4.1 (b)	2.2	2.4	1.9 (b)	1.8 (b)	6.2 (b)	4.7 (b)	2.6	6.6	2.7	6.0	4.0
% channel area pool	24	36	33	27	12	22	18	49	34	46	36	41	26	25
% channel area riffle	30	30	25	14	26	15	21	21	46	49	20	15	18	25
% channel in debris stored sediment	44	34	43	59	40	39	39	30	18	30	15	21	29	13
% channel area undercut banks	2	1	4	2	4	3	1	1	4	3	4	1	<1	1
% pool morphology influenced by debris	82	43	79	59	83	100	90	86	71	87	50	80	67	50
Debris controlled drop in elevation of the channel (%)(c)	57	37	69	17	38	59	30	43	27	34	8	<1	18	<1

(a) Total percentages in stream environments may be less or greater than 100% due to overlaps such as pools that contain debris stored sediment or existence of other environments not listed.

(b) Spacing controlled by organic debris.

(c) Ratio of cumulative loss of channel elevation associated with large organic debris to total fall of the stream reach.

Second growth redwood forest. It is classified as disturbed, as are the more recently logged Larry Damm Creek and Lost Man Creek watersheds.

LARGE ORGANIC DEBRIS AND ANADROMOUS FISH HABITAT

Residence Time of Large Organic Debris

The amount, arrangement, and residence time of large organic debris in a particular stream reach reflects intimate and complex relations between input and output processes, some of which are shown on Figure 2 (Keller and Swanson, 1978). The dominant process by which large organic debris may enter a stream channel depends on local geologic conditions. For example, on steep gradient sections of Little Lost Man Creek, landslides commonly deliver large organic debris to the channel. On the other hand, where tributaries enter Little Lost Man Creek along relatively low gradient sections or where streamside trees are rooted in thick soils, undercutting of the stream banks may be the dominant process that delivers large organic debris to the channel (Keller and Tally, 1979).

Large organic debris loading measured in kilograms of woody debris per square meter of active channel (kg/m^2), is determined by measuring the length and diameter of all large organic debris found in the active stream channel. In general, there is an inverse relationship between the stream size (drainage basin area) and the debris loading. This results because small streams tend to have small drainage basins, narrow valleys, steep valley slopes, and a relatively high frequency of landslides, all of which tend to increase the debris loading. Examination of Table 1, however, suggests that there is a great deal of variability in the debris loading of a particular stream. Much of the variability can be explained in terms of the proximity of large redwood trees to the stream channel. Where the density of large trees is relatively high the debris loading is higher than along sections of stream where there is a lower density of living redwood trees close to the channel. Data on Table 2 show the good correlation ($r = 0.88$) between debris loading and frequency of large trees within 50m on either side of the channel (Tally, 1980).

Table 2. Debris Loading and Frequency of Trees in the Vicinity of the Channel.

	Debris Loading (kg/m^2)	Tree Frequency	Flood Plain
Hayes Creek	170	68/ha	none
Little Lost Man Creek			
Upper	141.6	52/ha	none
Middle	268	40/ha	none
Lower	49.0	26/ha	none
Prairie Creek			
Hope Creek	218	80/ha	minor
Little Creek	12.3	25/ha	yes
Forked Creek	13.1	21/ha	yes
Zig Zag No. 2	21.7	25/ha	yes
Natural Tunnel	106	41/ha	minor
Brown Creek	84.8	75/ha	none
Campground	19.6	32/ha	yes

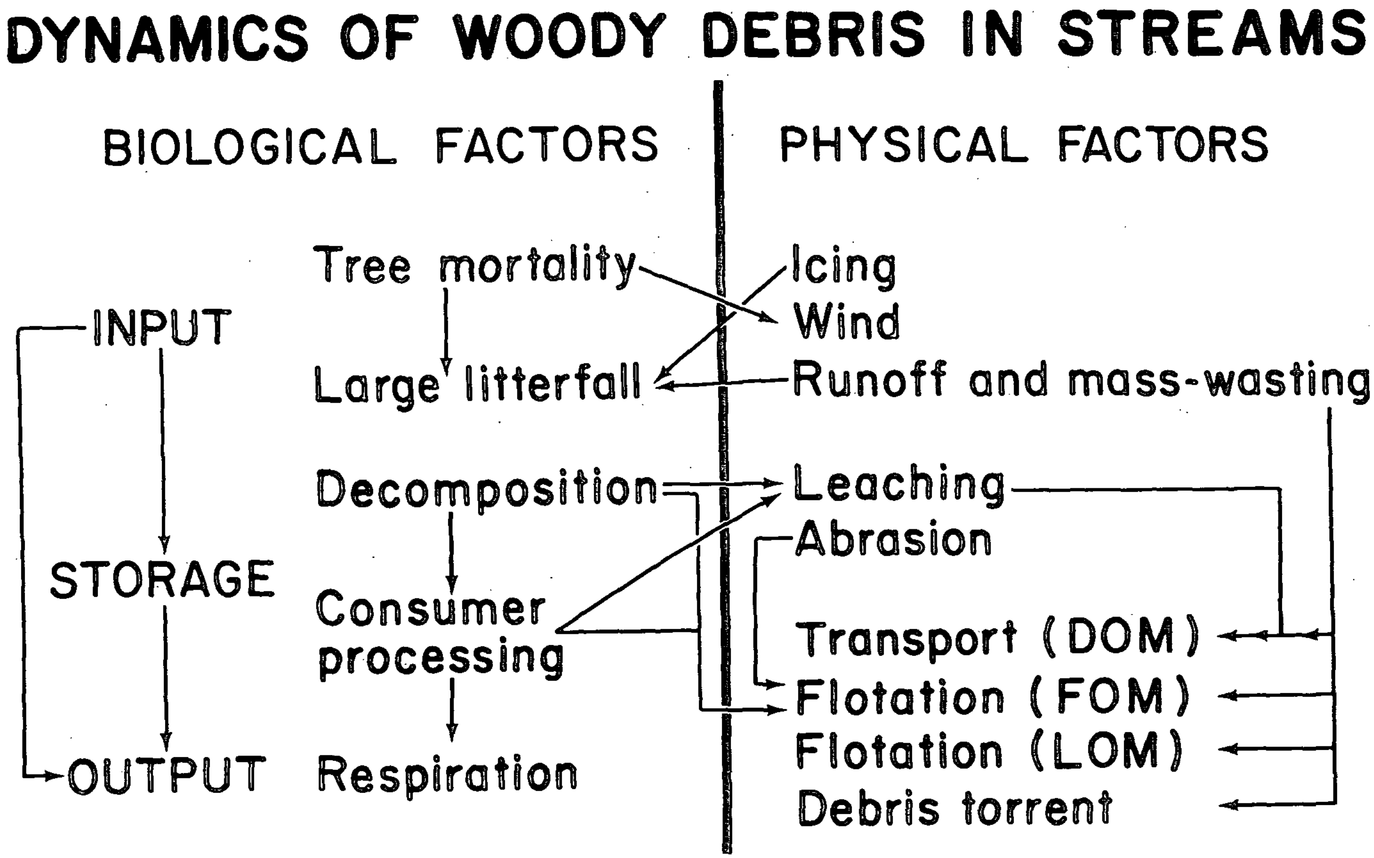

Figure 2. Keller, MacDonald & Talley

Movement of large organic debris through the stream system is primarily by flotation during high flows or perhaps, in very steep sections of the stream, by debris torrents (Swanson and Lienkaemper, 1978, and Keller and Tally, 1979). Large organic debris in streams draining old growth forest, such as Prairie Creek, Little Lost Man Creek, and Hayes Creek, may be very large, often several meters in diameter, and moves only rarely. This was determined by examining "nursed trees" such as hemlock, spruce, and other redwood trees that grow on downed trees. Coring of these "nursed trees" provides a minimum time that the debris has been in the stream channel. Table 3 lists selected examples of residency times in Prairie Creek and Little Lost Man Creek that exceed 100 years. In all, more than 30 pieces of debris have been dated and about half of these exceeded 100 years with the oldest exceeding 200 years. Based on this evidence, it is apparent that large organic debris resides in stream channels for several centuries and, thus, is a permanent part of the fluvial system. In larger streams such as the lower portions of Redwood Creek, there is sufficient water at high flow to float even the largest debris, and therefore the residence time is shorter. However, even here large organic debris greatly influences the formation of large pools and, thus, anadromous fish habitat.

Table 3. Minimum Ages for Large Organic Debris in the Study Reaches of Little Lost Man Creek and Prairie Creek: Selected Examples

Reach	Tree Type	Age (yrs)	Environment
Little Lost Man Creek			
Upper	Hemlock	130	Partial D.D.[a]/B.D.Tr.[b]
	Hemlock	135	Partial D.D./B.D.Tr.
	Hemlock	150	B.D.Tr. on Debris Stored Sed.
	Hemlock	185	Partial D.D./B.D.Tr.
	Hemlock	175	D.D.[c]
	Hemlock	200	D.D.
	Hemlock	105	D.D.
Lower	Redwood	220	B.D.Tr. downed trunk
	Redwood	100	D.D.
Prairie Creek			
Zig Zag No. 2	Sitka Spruce	150	B.D.Tr. with root mat
Brown Creek	Redwood	160	D.D.
	Hemlock	100	D.D.
	Hemlock	100	Partial D.D.
	Redwood	200	B.D.Tr. downed trunk
Campground	Redwood	100	Partial D.D.
	Hemlock	100	B.D.Tr. with root mat

(a) Partial D.D. = debris dam blocking part of channel
(b) B.D.Tr. = bank defending tree
(c) D.D. = debris blocking entire channel

Channel Morphology, Hydrologic Variability, and Anadromous Fish Habitat

Large organic debris in undisturbed streams provide hydrologic variability necessary for maintaining salmonid spawning and rearing habitat, while buffering sediment routing and discharge. Debris control of channel morphology is greatest in steep stream reaches and is most apparent in three categories: percentage of pools influenced by debris, extent of debris stored sediment, and debris control drop in elevation of the stream profile. Examination of Table 1 shows that 50-100% of pools in a given reach are created or enhanced by large woody debris. Examples of debris controlled channel morphology are shown on Figures 3, 4, 5, and 6 for Prairie Creek and Little Lost Man Creek, respectively. Examination of long profiles (Figures 5 and 6) illustrate the hydrologic variability (change in water depth or slope in the downstream direction) for the two study reaches. The ratio of cumulative loss of channel elevation associated with large organic debris to total fall of the stream reach (18% for the Brown Creek reach of Prairie Creek compared to 30% for the lower reach of Little Lost Man Creek, Table 1) is an indicator of potential energy loss (Keller and Swanson, 1979; Heede, 1981). That is, the large organic debris produces a stepped stream profile where a significant amount of a stream's potential energy may be dissipated at debris created falls and cascades which occupy a relatively small percentage of the total stream length. Thus, energy is expended at these locations rather than producing a generally deep incised channel with unstable and eroding channel banks. Little Lost Man Creek, in particular, has a relatively low sediment yield due in part to the existence of large organic debris which tends to preclude high erosion rates by forming accumulations of sediment that armors the stream bed and prevents deep incision. Similar observations by Heede (1981) for streams with smaller caliber large organic debris have been reported in the southern Rocky Mountains of Colorado and the White Mountains of Arizona. Examination of Table 1 reveals that up to about 60% of the drop along the stream profile for undisturbed basins may be due to large organic debris.

Although similar processes are operating in streams draining disturbed and undisturbed basins, the relationship between debris and channel morphology is somewhat different in the two cases. In undisturbed basins, channel morphology is more dependent on the frequency of debris than on the absolute amount. Thus, an old growth log large enough to be stable (generally greater than one bankful channel width and length) has about the same effect on the channel as one twice that size. On the other hand, debris loading in channels impacted by timber harvesting is dependent upon the timber harvesting methods employed rather than intrinsic basin characteristics. As a result, variability in debris loading in disturbed streams may be considerable and if large logs were removed from the channel during timber harvesting, then the caliber of the large organic debris found in the channel will be smaller than that found in undisturbed basins. Examination of Table 1 reveals that debris is only slightly less effective in controlling gross channel form in disturbed channels compared to undisturbed; however, the short-term stability of channel form is decreased in disturbed basins due to the higher percentage of unstable stored sediment.

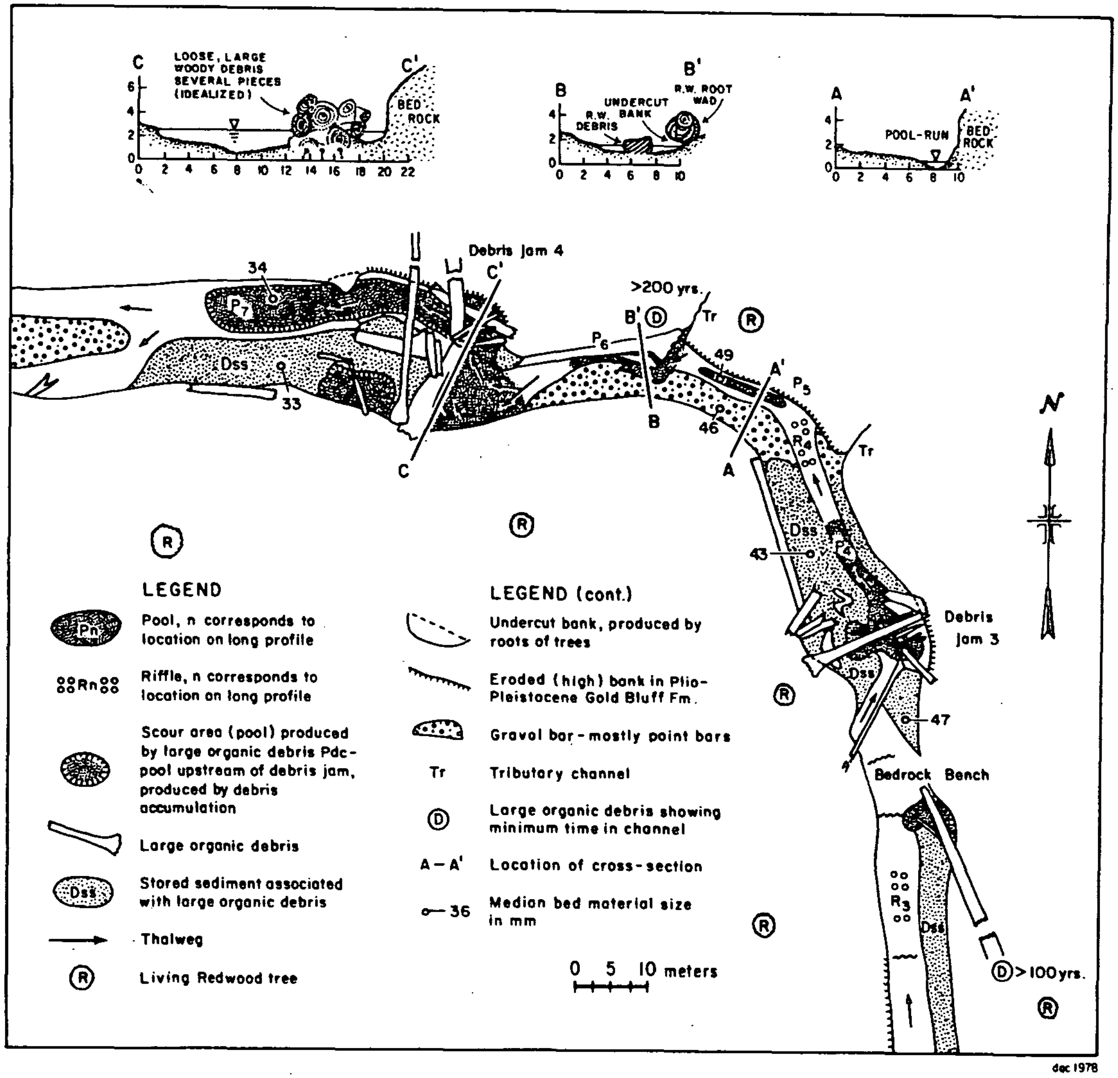

Figure 3. Keller, MacDonald & Talley

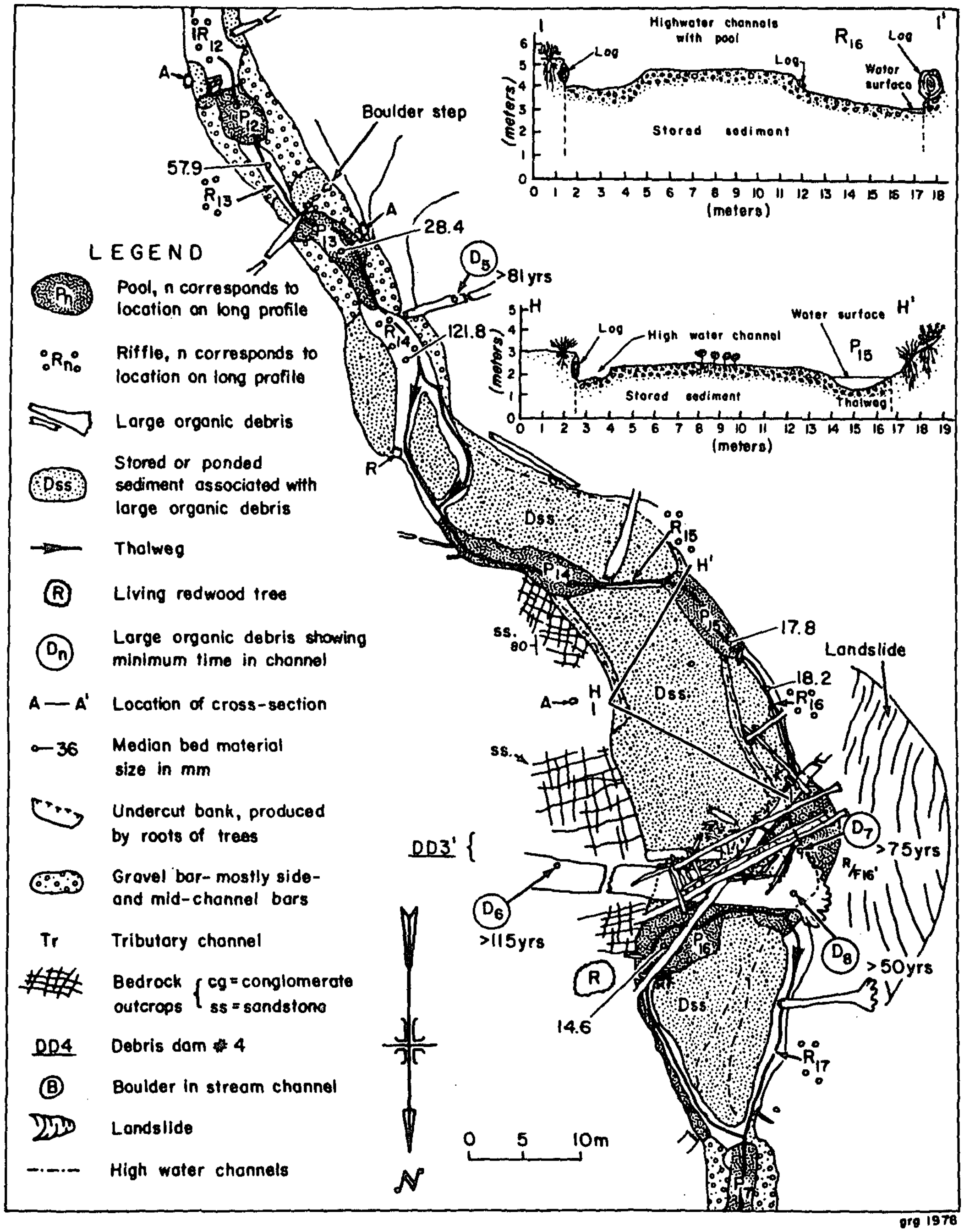

Figure 4. Keller, MacDonald & Talley

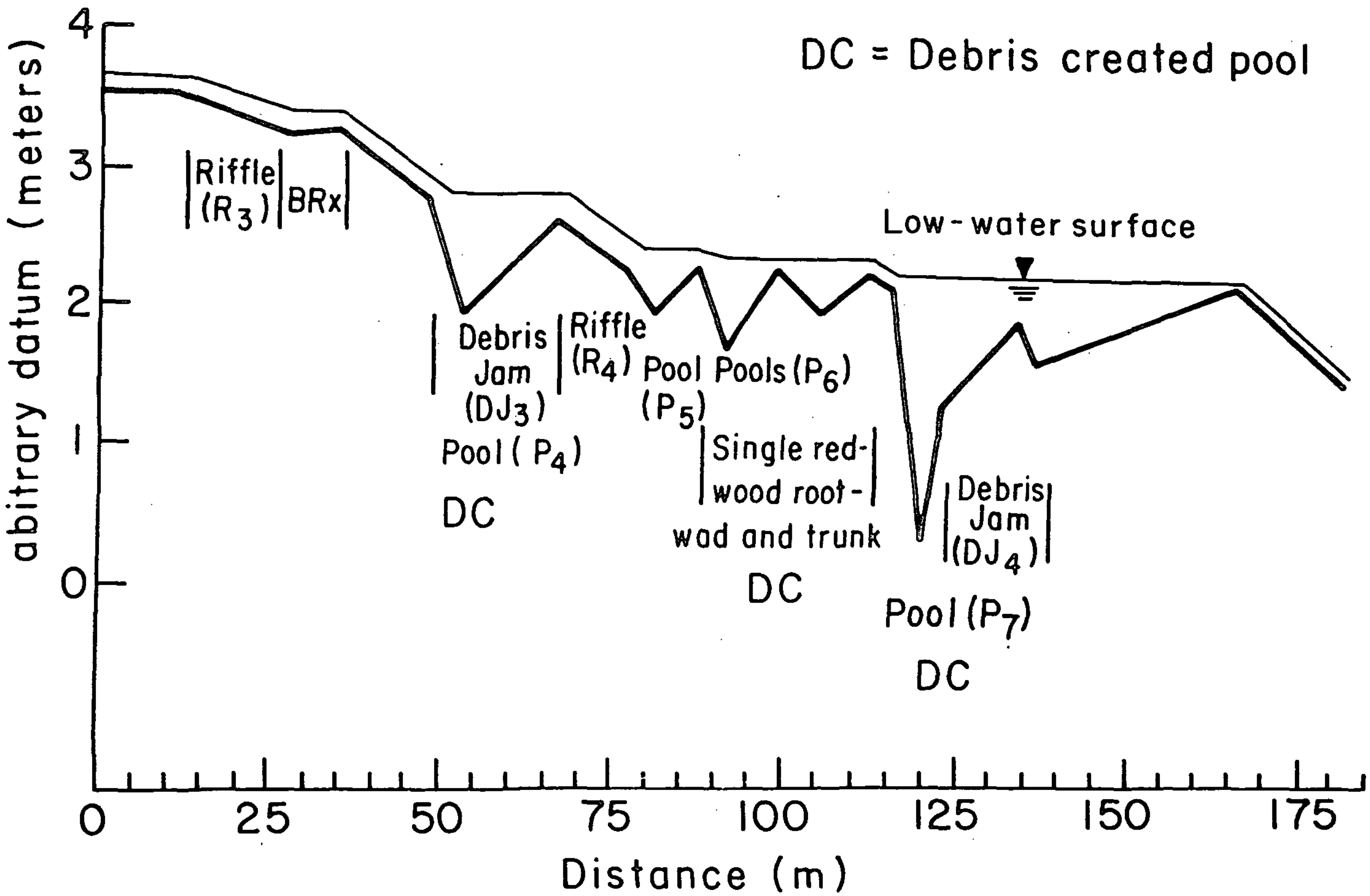

Figure 5. Keller, MacDonald & Talley

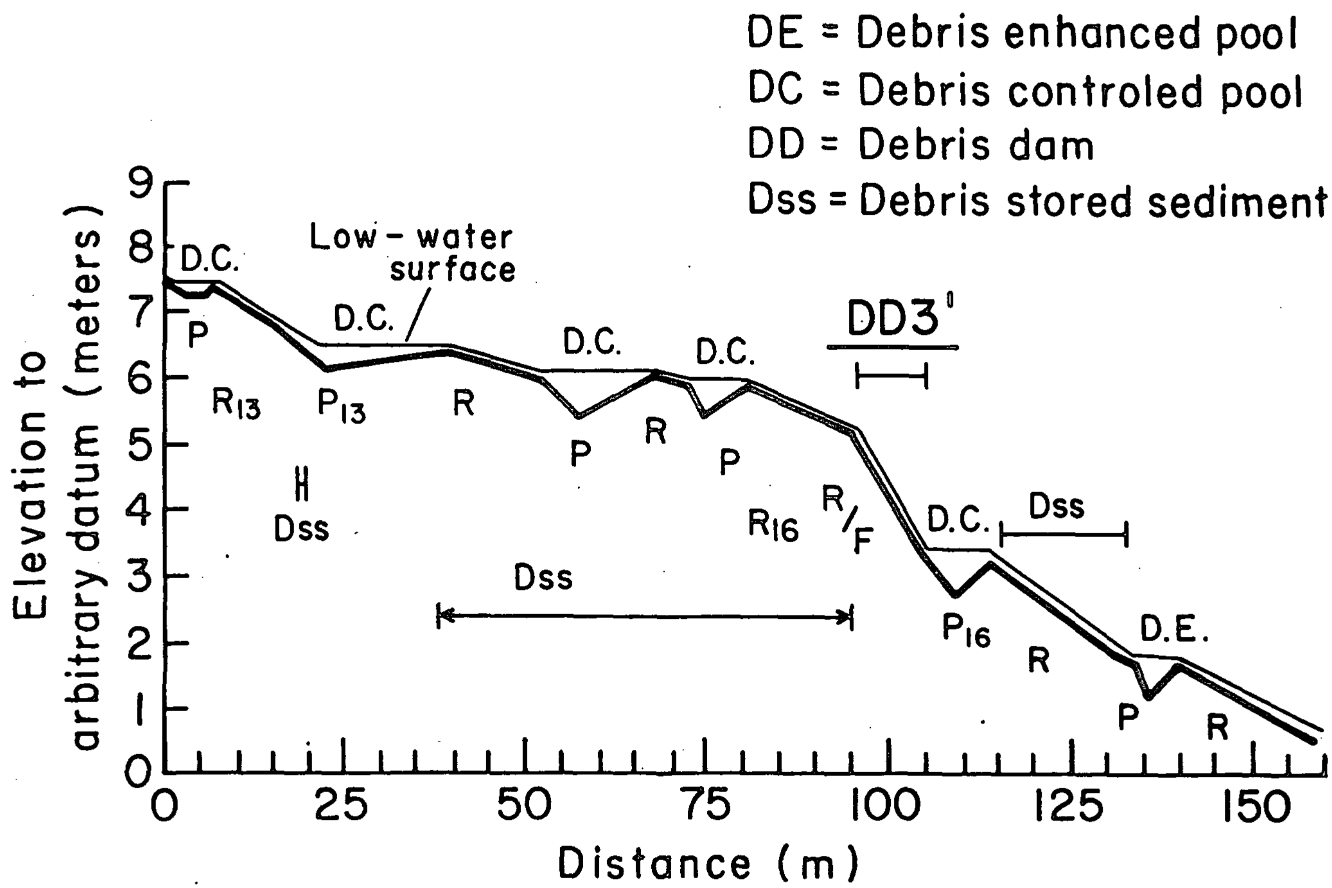

Figure 6. Keller, MacDonald & Talley

Sediment Routing: The Buffer System

Large organic debris plays an important role in the routing and storage of sediment. Debris accumulations such as organic steps produce storage compartments for sediment as ideally shown on Figure 7. Examination of Table 1 suggests that such storage sites account for a significant portion of the total channel area. In comparing disturbed and undisturbed watersheds, disturbed stream systems have a greater amount of debris stored sediment, probably reflecting that a greater portion of the storage compartments are filled. Studies by Megahan and Nowlin (1976) and Swanson and Lienkaemper (1978) suggest that annual sediment yields in small forested watersheds are generally less than 10% of the sediment stored in channels. In comparison, in Little Lost Man Creek, where 40% of the active stream channel is in debris stored sediment, the storage compartments are considerably larger; this probably reflects the difference in size of organic debris producing the compartments. The average annual suspended sediment yield for the Little Lost Man Creek basin is about 450 metric tons and approximately 25% of this is bedload, providing an average annual bedload yield of approximately 116 metric tons. The total debris related sediment volume in Little Lost Man Creek is estimated to be approximately 14,000 m^3 and approximately 64% or 8,950m^3 of this is presently full. Assuming a unit weight of debris stored sediment consisting of gravel and sand to vary between 1.36 and 2.00 tons per cubic meter (Geiger, 1965), approximately 100 to 150 years of average annual bedload sediment yield is stored in debris related sites along Little Lost Man Creek and about 50 to 100 years of average annual bedload yield is available for future storage. Thus, if the storage system were filled to capacity, it would contain from 150 to 250 years of average annual bedload yield. This should not be interpreted to mean that the sediment storage compartments associated with large organic debris effectively trap all of the bedload that moves into a particular reach. In fact, debris stored sediment tends to be significantly finer gravel than that found on riffles on Little Lost Man Creek. Furthermore, because it is finer, it tends to be transported more frequently in response to moderate flow (50% of bankfull, a discharge with recurrence interval of about 1.5 years), whereas coarse material on riffles tend to armor the bed and is probably moved only during extreme events (Tally, 1980). Evidence from streams in New Zealand suggest that sediment that moves out of a debris stored site will usually only move a short distance before being redeposited behind downstream debris accumulations (Mosley, in press).

The important principle concerning debris stored sediment is that the accumulative storage sites define a buffer system that modulates the movement of bedload through the fluvial system. As a result, the output or release of sediment from the watershed which may have been added during an extremely short period of time, will be spread out over a relatively long period. Thus, if a number of landslides develop in response to a high magnitude-low frequency storm, the sediment input from those landslides may take many years to move through the system. This also has important ramifications for watersheds impacted by land use change such as road building or timber harvesting. As the sediment is input into the system, there will be a lag time before the sediment yield or output increases significantly. However, once the storage sites are full, then sediment will be transported more directly down the channel through the full storage sites.

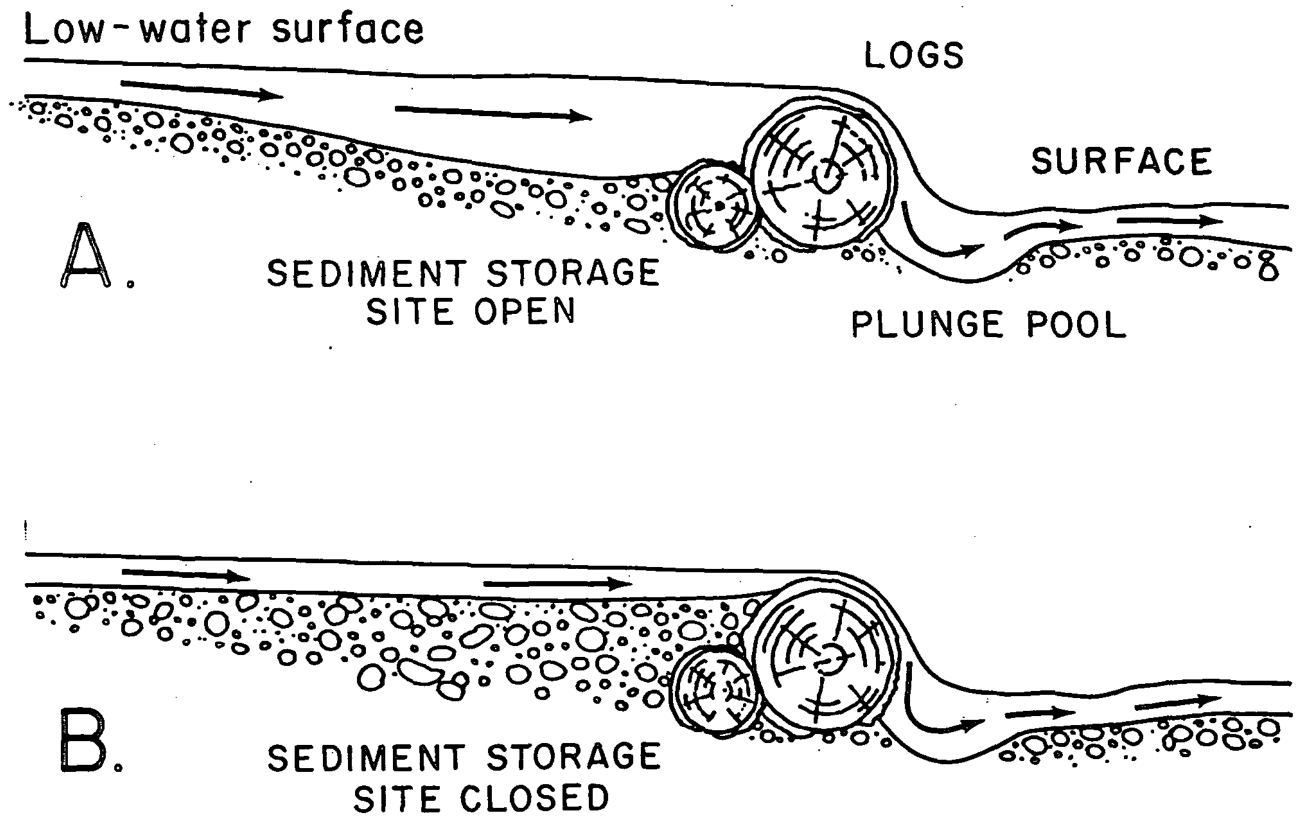

Figure 7. Keller, MacDonald & Talley

LARGE ORGANIC DEBRIS AND MANAGEMENT OF ANADROMOUS FISH HABITAT

Management of streams, to maximize production of anadromous fish in the coastal redwood environment, should consider the entire fluvial system including the role of large organic debris. Occasionally, large organic debris may block fish migration and cause adverse channel erosion. Such accumulations (especially when delivered to the stream channel in response to land use change) should be removed following the development of a specific plan for that site. However, within limits, large organic debris is necessary for a biologically productive stream environment. Therefore, stream clearing operations must carefully weigh the benefits of locally stabilizing stream banks, opening up stream anadromous fish habitat or marketing merchantable timber with potential dangers in losing hydrologic variability and mobilizing large quantities of bed material that has been in storage sites produced by large organic debris.

In dealing with watersheds with old growth timber, it is probably best to not remove large organic debris that falls into the stream channel. There is sufficient evidence to support the conclusion that the debris helps create fish habitat by providing cover and pool environments for juvenile anadromous fish. Furthermore, debris removal is expensive and may damage adjacent areas in the riparian zone.

In managing streams impacted by timber harvesting, removal of large logs and slash introduced by logging may be necessary. Such removal should only involve logs placed into the stream by the logging and should not extend below the level of the natural stream prior to disturbance. Overzealous removal of large organic debris will result in damage to the fluvial system.

Management plans in dealing with large organic debris should strive to duplicate natural processes found in undisturbed basins. This philosophy puts forth a "design with nature" approach recognizing that the natural fluvial system has evolved over hundreds and thousands of years in response to the presence of large organic debris. It also recognizes that removal of the debris may result in problems equal to or exceeding the problems presumed associated with unwanted debris. The more we learn about large organic debris, the more we recognize that it is intimately related to the fish habitat and thus production of anadromous fish. In many subtle ways the debris is interacting in positive ways to produce and maintain desired fish habitat, particularly the low flow summer habitat. Therefore, until we learn even more concerning the role of large organic debris, a very conservative practice conerning its removal should be set forth.

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