

Effects of Large Organic Debris on Channel
Morphology and Process, and Anadromous
Fish Habitat in Steep Mountain, Coast
Redwood Environments

by

Nancy J. Merritt

Hanes Cr. Study

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ABSTRACT

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The Coast Redwood Forest is a unique and sensitive ecosystem. An intricate system of interaction exists between the hillslope, floodplain, and stream environments, as well as between the components within each of these environments.

The channel form and process of steep mountain streams flowing through old-growth, redwood forests are strongly affected by large organic debris, especially in small to intermediate sized streams. In particular, large organic debris plays an important role in the formation of channel characteristics such as width, depth, and gradient. Diverse channel erosion-deposition patterns and sediment storage sites also result from the interaction between large organic debris and the fluvial system.

Debris is supplied to the channel environment by the riparian vegetation, and the total debris loading within the stream is a function of the delivery and removal rates of organic debris. The debris loading in the study reaches of Hayes and Little Lost Man Creeks

exemplify the inverse relationship between stream size and debris loading, and the direct relationship between stream order and size, complexity, and spacing of debris dams.

The longitudinal profile of steep mountain streams takes on a stepping pattern due to the presence of large organic debris within the channel. The scour pools and sediment storage sites associated with these steps help provide habitat for anadromous fish populations. Rearing grounds are supplied by the scour pools, and sediment storage sites maintain prime spawning grounds by regulating the amount of sedimentation in the riffle areas.

Anadromous fish populations depend upon a stable balance within the forest ecosystem, however, timber harvesting disrupts that balance. A management program must be implemented in order to minimize the adverse effects of timber harvesting. This management program must consider the interrelationship between the hillslope, floodplain, and stream environment, and between large organic debris and the fluvial system. A follow-up plan must also be included in order to assure that proper management is actually practiced by loggers.

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INTRODUCTION

Northwestern California contains a significant proportion of the state's commercial forest lands (Fig. 1). In Mendocino, Humboldt, and Del Norte counties,

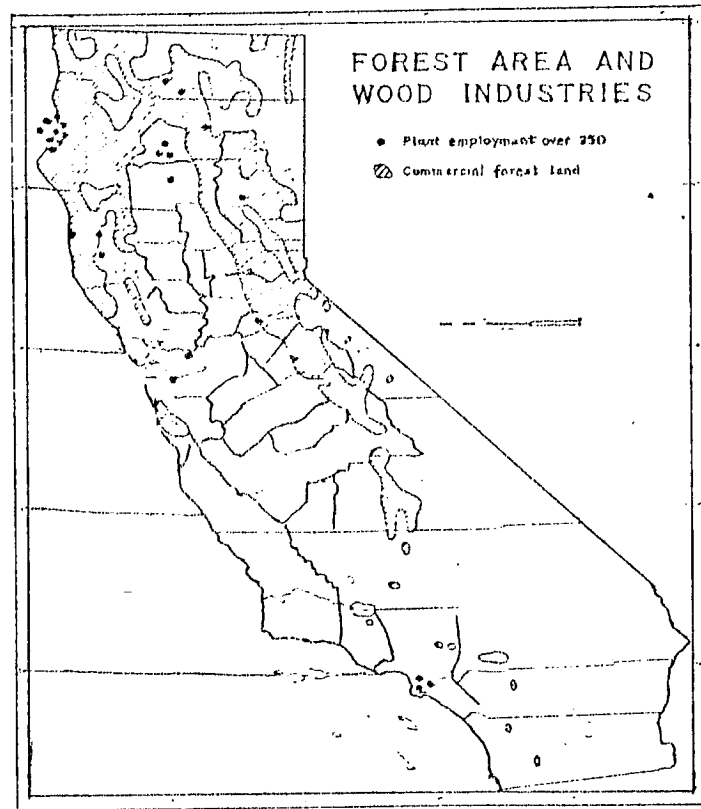


Fig. 1. Map of commercial forest lands
(After Lantis, Steiner, and Karinen, 1977).

local economies heavily rely upon resources from these forested areas. Major contributors to the economies of these counties are lumbering, and sport and commercial fishing.

Forestry is, by far, the primary source of livelihood in northwestern California. The Coast Redwood was once the principal lumber source for the logging industries in Mendocino, Humboldt, and Del Norte counties. However, more than 90% of the virgin redwood stands have been logged since operations commenced more than a century ago (Lantis, Steiner, and Karinen, 1977). Today the industry depends on Douglas Fir for its primary supply of lumber. Redwood and Douglas Fir stands are predominately logged by clearcutting--a method which drastically alters the channel, floodplain, and hillside environments of the forest ecosystem.

Fishing, both sport and commercial, is also a major industry in these three northern counties. Anadromous fish such as salmon and steelhead trout are popular sport fish as well as important commercial fish. Fresh water streams flowing through the forest ecosystem perform a vital function in maintaining the anadromous fish populations. The stream's pool-riffle sequence provides spawning grounds and protective areas for the younger fish (Fig. 2). The riparian vegetation controls stream quality by stabilizing streambanks, contributing nutrients to the stream, and by offering shade for temperature regulation.

Both fishing and lumbering industries rely upon interrelated components of the forest ecosystem--the channel, floodplain, and hillslope environments. These

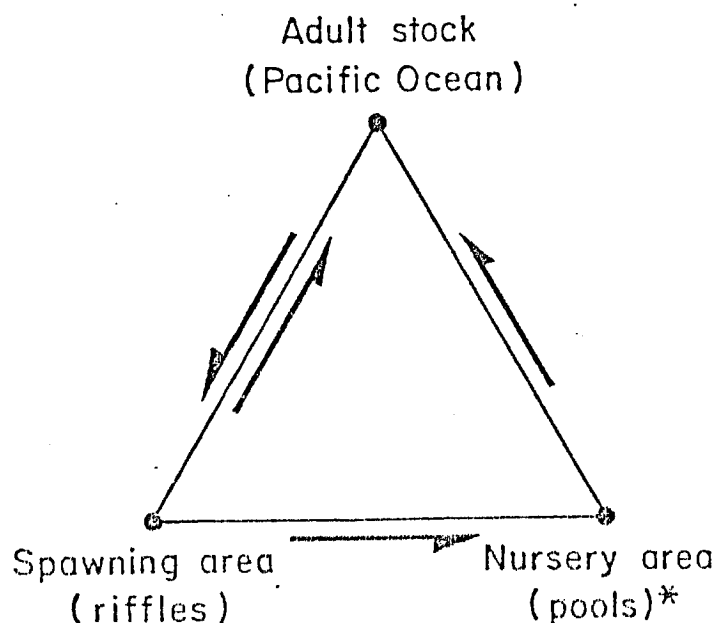


Fig. 3. Life cycle of anadromous fish. *Role of large organic debris is very important with respect to the formation and maintenance of pools (After Keller, personal communication).

environments attained a delicate balance after millions of years of meticulous evolution. During this time these components of the forest ecosystem acquired the necessary mechanisms to harmoniously adjust in order to maintain stability within the system.

Harvesting of timber resources disrupts the natural balance of the forest ecosystem, and thus conflicts with the needs of the fishing industry. The protective canopy of the riparian vegetation, water quality, and abundant spawning and rearing grounds must be maintained in order to supply the needs of the anadromous fish populations. Logging disrupts the natural balance of the forest ecosystem by removing vegetation, polluting the streams with large quantities of sediment, and by reducing the

diversity of habitats for aquatic organisms. In order for these two industries to coexist, a proper management program must be established.

The purpose of this paper is to examine the natural fluvial system in virgin redwood forests with respect to the development and maintenance of anadromous fish habitats and timber harvesting. The effects of large organic debris on channel form and fluvial processes will be concentrated on in this paper. In particular, the effects of large organic debris on channel width, depth, and slope; pools and riffles; and areal sorting of bedload material will be discussed.

THE COAST REDWOOD ECOSYSTEM

The Coast Redwood (*Sequoia Sempervirens*) discontinuously parallels the California and southern Oregon coastline, and extends inland approximately 40 kilometers (Fig. 3). The majestic Coast Redwood is commonly known as the "Tallest Living Thing"--mature trees attain heights of 90 to 100 meters, and the tallest tree is recorded at 112 meters; diameters range from 3.5 to 5 meters (Simmons and Vale, 1975).

Dense stands of old-growth redwood produce an exceedingly beautiful, cathedral-like environment. Tree densities in Coast Redwood Forests are 50 to 125 per hectare, and the average age of the Coast Redwood is

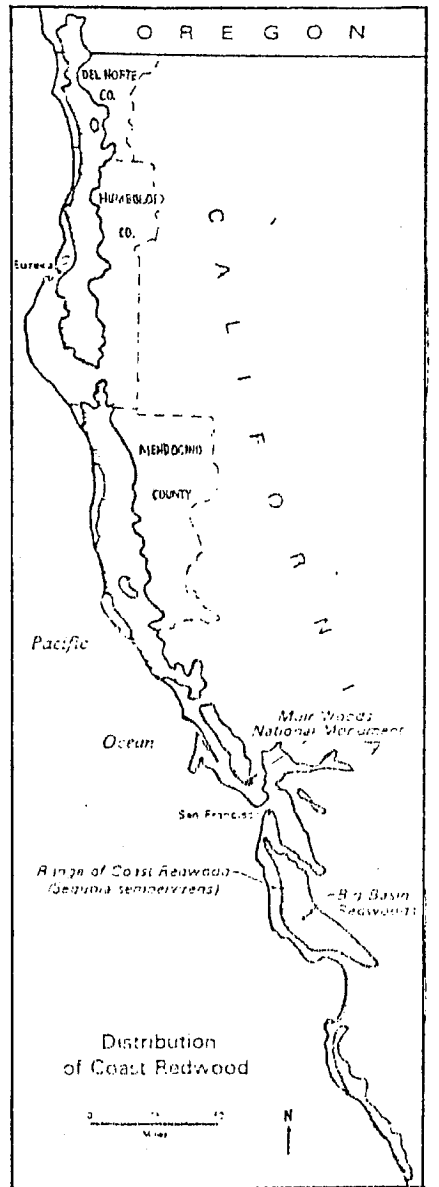


Fig. 2. Range of the *Sequoia sempervirens* (After Simmons and Vale, 1977).

approximately 600 years, with some ranging up to 1,600 years (Viers, 1978).

The redwood forest ecosystem is divided into three components--the hillslope, floodplain, and channel environments. The overstory and understory vegetation of the hillslope region offer support to the steep valley slopes

by (1) increasing the shear strength of the soil with their interlocking root systems, (2) supplying the forest floor with a thick layer of decomposing organic detritus which minimizes storm runoff and erosion of the topsoil, as well as (3) constantly monitoring the watertable through transpiration.

All floodplain vegetation, as well as a portion of the trees on hillslope areas, make up the riparian vegetation (Fig. 4). The riparian vegetation marks the

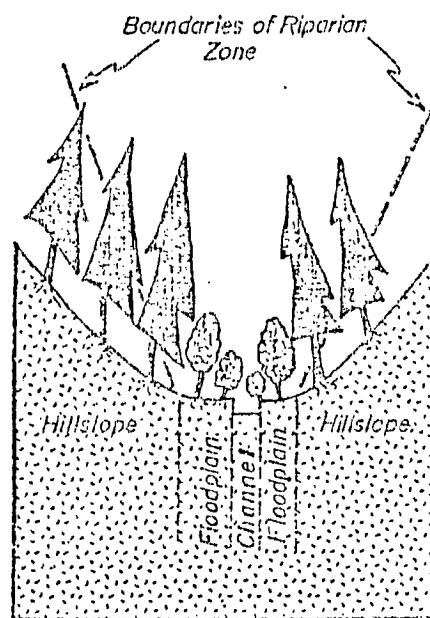


Fig. 4. The extent of the riparian zone, and the hillslope, floodplain, and channel environments of the forest ecosystem (After Meehan, Swanson, and Sedell, 1977).

interface between the stream and terrestrial environments, and plays an important role in the redwood forest ecosystem.

The dense, low-lying understory and canopy of the stream-side vegetation act as a filter to inhibit the entry of sediment and debris from upslope locations. The root systems of the trees and shrubs minimize stream erosion, and stabilize undercut streambanks providing protective habitat for resident and anadromous salmonoids. The riparian vegetation also contributes organic detritus and insects to the food base of stream organisms, as well as large organic debris to the stream environment (Fig. 5).

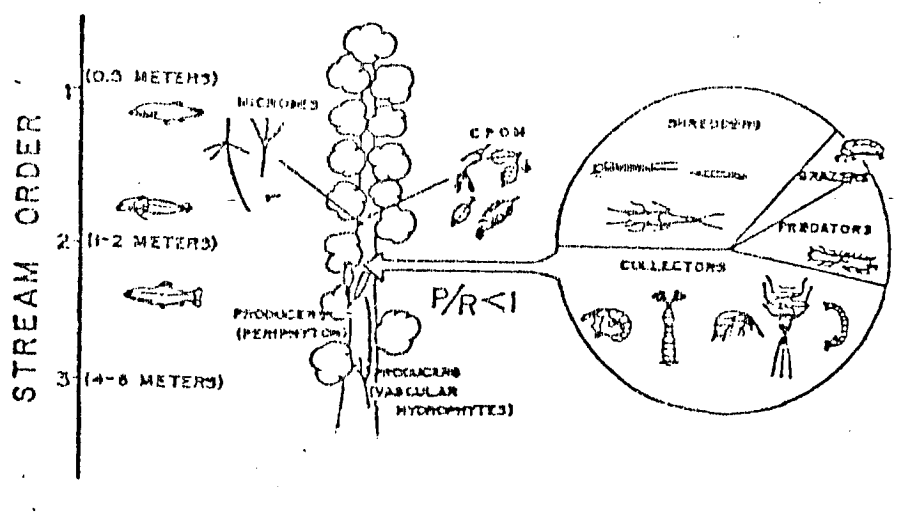


Fig. 5. Coarse particulate organic matter (CPOM) in the stream channel provides a food base for shredding, collecting, and grazing insects which supply a food base for predatory insects. In turn, all of these insects provide a food base for resident and anadromous fish. (After Meehan, Swanson, and Sedell, 1977.)

In addition, the canopy cover of the riparian vegetation insulates the aquatic environment from direct solar radiation, and thus, regulates water temperature. Shading produced by the canopy cover is of extreme importance in small forested streams where susceptibility to temperature fluctuation is the greatest, and where significant proportions of salmon and trout populations are cumulatively produced (Meehan, Swanson, and Sedell, 1977). Temperature fluctuations have a significant impact on spawning, incubation, and rearing of anadromous and resident fish.

Rainfall in the Coast Redwood ecosystem is abundant, with precipitation ranging from 51 to 258 centimeters per year (Simmons and Vale, 1975). The channel environment serves as a mechanism for the collection and movement of excess water in the forest system, as well as a habitat for aquatic organisms. The varying channel morphology provides diverse habitats for aquatic insects and other organisms, and stabilizes the food chain of the aquatic faunal community.

RESEARCH AREAS AND METHODS

Hayes Creek and Little Lost Man Creek study reaches are located within Redwood National Park, approximately 70 kilometers north of Eureka, California (Fig. 6). Both of these study reaches flow within virgin redwood forests. Hayes Creek, a tributary to Redwood Creek, is a second

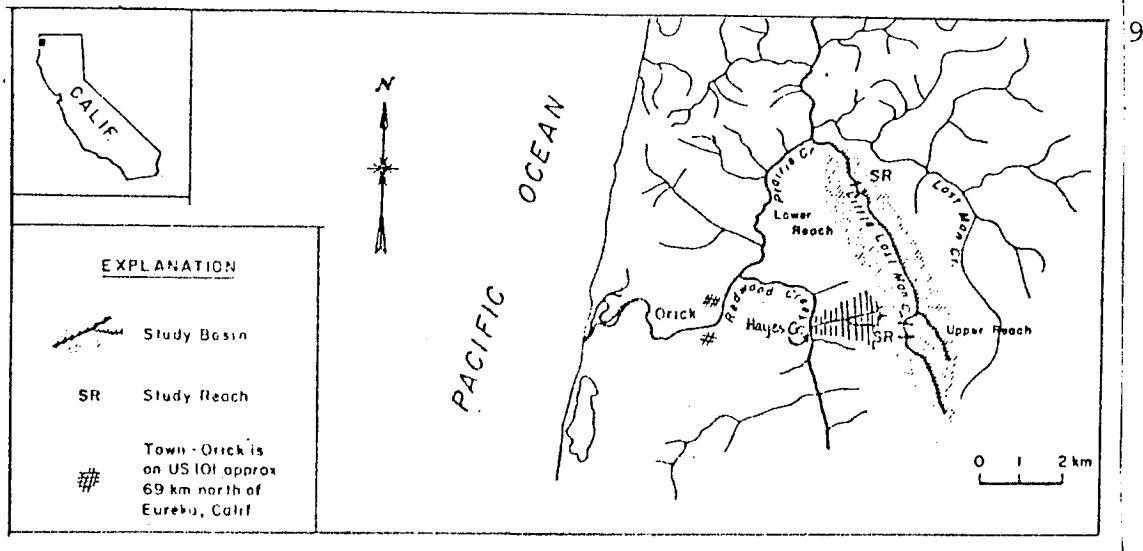


Fig. 6. Index map of Hayes Creek and Little Lost Man study reaches.

order steep mountain stream, and flows over a combination of sedimentary and high grade metamorphic rocks. Little Lost Man Creek is also a steep mountain stream, but of third order. This creek flows over steeply dipping sedimentary rocks of the Mesozoic Franciscan Formation.

Hayes and Little Lost Man Creeks were studied during summer low-flow conditions. Research was done by surveying longitudinal and cross-channel profiles, constructing morphologic maps, measuring debris loading, and analyzing areal pebble size distributions.

LARGE ORGANIC DEBRIS: PROCESS AND LOADING

The large organic debris in stream channels is supplied by hillslope and floodplain vegetation. Redwood, Douglas Fir, hemlock, big leaf maple, and alder are the species of trees which contribute to debris

loading in Coast Redwood forests. Natural processes responsible for the delivery of large organic debris into the stream environment consist of mass wasting, bank erosion, and windfall. Entry of large organic debris by landsliding dominates the upper portion of Hayes Creek study reach (refer to morphologic map, Plate 1, in pocket). Steep valley slopes and the lack of a distinct floodplain are responsible for the susceptibility of this section to bank undercutting and mass movement.

Disruption of channel flow characteristics by the entry of large organic debris can perpetuate the delivery of more organic debris into the stream system. For example, the changes in erosion and deposition patterns induced by a windfallen tree can initiate bank erosion and failure, and thus the delivery of more organic debris into the channel.

Removal of organic debris occurs through any of three processes--decay, erosion, and flotation. The residence time of large organic debris depends on how susceptible the debris is to these processes. Redwood, by far, is the dominate large organic debris found along Hayes Creek. This is a function of redwoods being so highly resistant to decay, and lower order streams having smaller discharges and being less capable of transporting large old-growth redwoods by flotation.

Debris loading within a stream is determined by the delivery and removal rates of that stream, and is calculated

by actually measuring the length and diameter of all large organic debris within the stream channel. Large organic debris is considered to be any debris greater than 10 centimeters in diameter; measurements are in kilograms per square meter of active channel (kg/m^2).

Due to the large size of the old-growth redwoods, a significant proportion of the total debris loading may be due to one large trunk. Along the 138-meter reach of Hayes Creek, 25% of the total debris loading is accounted for by one redwood trunk, and about 50% consists of three redwood trunks. Upper Little Lost Man Creek has 60% of its total debris loading along a 400-meter reach tied up in one trunk, and a value almost as high as 80% for two trunks (Keller and Tally, 1979).

Hayes Creek is a second order stream with a slope of .12, and a 1.5 km^2 upstream drainage area. Debris loading along the Hayes Creek study reach is 170.0 kg/m^2 , and occurs as simple debris accumulation, but more commonly as scattered large trunks and splinters (refer to morphologic map). Two relatively complex debris accumulations also occur within this reach (DD1 and DD3).

The upper reach of Little Lost Man Creek is also second order, however, the slope is .033, and the upstream drainage area, 3.5 km^2 . Debris loading, 141.6 kg/m^2 , is lower than Hayes Creek, but of the same magnitude. Organic debris occurs mainly as scattered large trunks and

splinters, with a few small simple accumulations, as in Hayes Creek. In contrast, the lower, third order reach of Little Lost Man, with a slope of .048 and an upstream area of 9.2 km^2 , has a lower debris loading of 49.0 kg/m^2 . Debris accumulations are larger, more complex, and are spaced further apart.

The similarities and differences between Hayes Creek and the upper and lower reaches of Little Lost Man Creek correspond to results from previous studies. Keller and Tally, 1979, noted the inverse relationship between stream order and debris loading. This relationship is a function of in-channel debris having a greater chance of removal (by flotation) with increased discharge downstream. Debris loading in second order Hayes and Upper Little Lost Man reaches is approximately 3 times greater than in third order Lower Little Lost Man. The general tendency for debris accumulations to increase in size, complexity, and spacing (Tally, MacDonald, and Keller, 1979) is also exemplified in these three study reaches. Lower Little Lost Man has distinctly larger, more complex, and further spaced debris accumulations than Hayes or Upper Little Lost Man.

CHANNEL FORM AND PROCESS

Channel morphology and fluvial processes in small to intermediate sized streams are greatly influenced by

large organic debris deposited into the stream environment (Keller and Tally, 1979). The amount of influence exerted is a function of the quantity of organic debris within the stream. Since debris loading is higher in lower order streams, the extent to which large organic debris influences these streams is greater.

Other factors, which determine the degree to which channel form and process are affected, are the complexity and orientation of the debris. Large organic debris may occur as single trunks, or as simple to complex accumulations. The debris may be oriented such that it lies completely across the channel, extends only part way into the stream channel, or lies parallel to the stream banks --each having a different impact on channel form and process.

Slope. Channel slope is a direct result of the stream's efforts to minimize energy expenditure and at the same time transport the sediment delivered to the channel. Variables which affect the attainment of this compromise include, among others, large organic debris, boulders, bed particle size, peak and mean annual water and sediment discharges, and geology. All variables are probably not of equal importance; this discussion will concentrate on large organic debris.

Large organic debris which extends across the entire width of the channel has the most significant impact on

the stream gradient. These types of debris dams restrict stream flow thus provoking considerable changes in stream process, which may be manifested in slope adjustments. Stream flow is able to divert around large organic debris which extends into only part of the stream channel or which parallels the banks, and undergoes fewer changes in doing so, resulting in less significant adjustments to the stream gradient.

Streams develop a slope which provides the velocity of water necessary to do the work of moving the sediment load (Mackin, 1948). When large organic debris extends across the width of the stream channel it hinders stream flow and the stream's ability to transport its sediment load, thus initiating slope changes. Upstream from the organic debris stream flow is reduced, resulting in the deposition of sediment and the net effect of increasing the gradient downstream. The sediment-deficient water flowing over the organic debris scours the stream channel, causing a decrease in gradient to result. These adjustments continue until a new balance is achieved.

The slope of Hayes Creek study reach is .12 and 38% of the drop is associated with large organic debris. The longitudinal profile of Hayes Creek (Plate 1) shows the typical stepped pattern of debris laden streams. This stepped profile is of extreme importance with respect to bank stability and sediment transport--a significant

proportion of downstream potential energy is lost along these debris associated drops, leaving less energy available to erode the stream bed and banks; sites upstream from the debris provide temporary storage areas for sediment, thus regulating its discharge (Keller and Swanson, in press).

Channel Width and Depth. Channel widening and deepening occur mainly during peak discharges, and are controlled by factors such as geology, amount, and positioning of large organic debris and sediment discharges, which influence the direction of flow and the amount of scour. The role of large organic debris in shaping channel width and depth is of considerable interest in small to intermediate sized streams in forested environments, where debris loading is highest.

Large organic debris, and living trees in close proximity to the channel, help to stabilize channel banks and minimize widening. Large trunks embedded in or lying adjacent to the edge of the stream stabilize the banks by armoring them from erosion. Between DD1 and DD2 along Hayes Creek (Plate 1) approximately 22 meters of stream bank (almost 4.5 times the average width of the stream) are armored from erosion by large redwood trunks within the stream channel. Rootmats of living trees in close proximity to the channel also help to stabilize banks. Downstream from DD3, the extensive rootmat of a very large,

old-growth redwood is helping to minimize stream erosion along the bank. This armoring effect is the result of the trunks and roots of trees being more resistant to erosion than unprotected banks.

Large organic debris that extends only part way into the channel may increase stream bank erosion by re-directing the flow of water against the banks, enhancing undercutting. This loss of lateral support results in the failure of the stream bank, and the widening of the channel. For example, some of the redwood trunks which armor the southern bank of Hayes Creek between DD1 and DD3 are extending part way into the channel, causing the flow of water to be directed into the northern bank, with erosion and widening resulting.

Large organic debris lying completely across the channel width may either stabilize or facilitate erosion of channel banks by producing either convergent or divergent flow, resulting in a locally narrower or wider channel (Keller and Tally, 1979). When streamlines of flow converge under the debris, energy is directed away from the channel banks, and a locally narrower channel results (see DD5, Plate 1, for example). However, when streamlines of flow diverge outward towards the banks, undermining and subsequent bank failure cause widening of the channel (see DD1, Plate 1, for example).

Large organic debris is largely responsible for

the variability in channel depth along steep mountain streams. The organic stepping pattern, formed by large organic debris in the stream channel, produces shallow depths in areas of debris stored sediment, and deeper areas--scour pools--at the base of the organic steps. The variable depths which result provide a variety of habitat for aquatic organisms. Without the presence of large organic debris and the production of the organic stepping pattern, the stream could effectively become "channelized." This would result in the more rapid transfer of sediment and a decrease in habitat variability, upon which the forest stream's biological community is dependent (Keller and Swanson, in press).

Within the Hayes Creek study reach, 83% of the pools are influenced by large organic debris, and depths of the pools vary from 0.10 to 0.55 meters during low-flow conditions. The remaining pools are influenced by large boulders which are common throughout most of the study reach. Upper and Lower study reaches of Little Lost Man Creek have 100% and 90%, respectively, of their pools influenced by large organic debris. The slightly lower percentage of pools influenced by large organic debris in Hayes Creek can be accounted for by the shorter length of the study reach and the significant role of boulders in influencing pool morphology.

Erosion and Deposition Patterns. Channel bed forms

are produced by stream erosion and deposition, and are characterized by features such as pools, riffles, boulder runs, boulder stored sediment, and in streams influenced by large organic debris, scour pools, and debris stored sediment. Channel variability produced by these diverse bed forms helps to maintain a healthy stream environment by providing a variety of flow conditions and habitats for aquatic organisms.

The pool environments in Hayes Creek and Little Lost Man Creek are primarily related to organic stepping. These topographically low areas are developed during high flow due to corrasion of the channel bed by cascading, sediment deficient water, and are characterized during low flow by deep, slow moving water. The average spacing of the pools in Hayes and Little Lost Man Creeks reflects the spacing of the organic debris, and is equal to approximately two channel widths. Debris stored sediment typically associated with organic stepping accounts for approximately 40% of the total channel area in both Hayes and Little Lost Man Creeks.

Riffles, as well as boulder runs in Hayes Creek, are topographic high areas and are produced by deposition during high flow. These riffle and boulder run areas are characterized during low flow by relatively rapid, shallow flow. In Hayes Creek, riffles account for 25% of the total channel area; boulder runs, 19%; and pools, 12%.

Boulder runs are lacking in the study reaches of Little Lost Man Creek, however, riffles cover 21% of the stream channel, and 18 to 22% for pools. Boulder stored sediment within Hayes Creek study reach covers approximately 2% of the total channel.

Areal distribution of bedload material is important with respect to the hydraulic processes associated with erosion and deposition patterns. Data reflecting the patterns of sorting along Hayes Creek were obtained by sampling bed material in six locations, following methods outlined by Wolman (1954). Areal sorting is not extensively developed along the Hayes Creek study reach, as seen by viewing the morphologic map. Sediment size distributions of debris stored sediment and sediment located in pool areas show only slight variations--debris stored sediment tending to be slightly finer, and slightly less sorted (Figs. 7-12). Riffle material tends to be coarser, whereas bed material from boulder runs is distinctly coarser and more poorly sorted.

ANADROMOUS FISH AND TIMBER HARVESTING

The interactions between large organic debris and the fluvial system within the forest ecosystem is of vital importance to anadromous fish, such as steelhead trout and salmon. As seen from the previous discussion, the interactions between large organic debris and channel

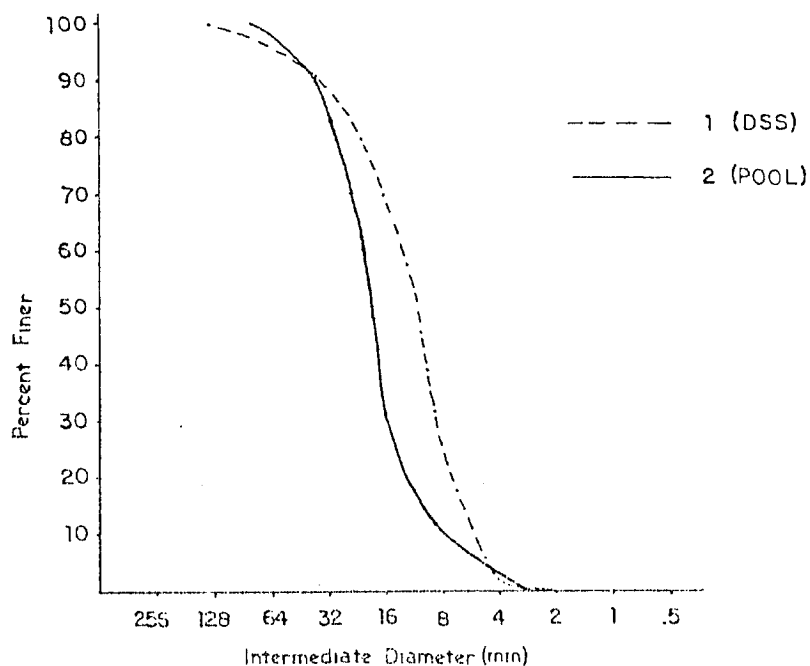


Fig. 7a. Grain size distribution at Sample Sites 1 and 2.

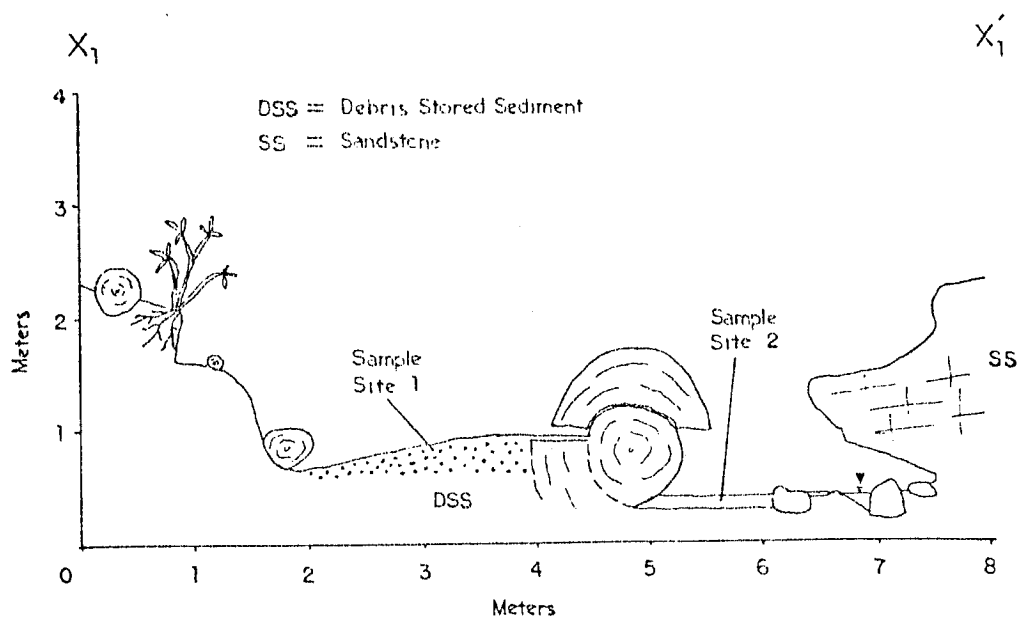


Fig. 7b. Cross section at Sample Sites 1 and 2: DDS and pool.

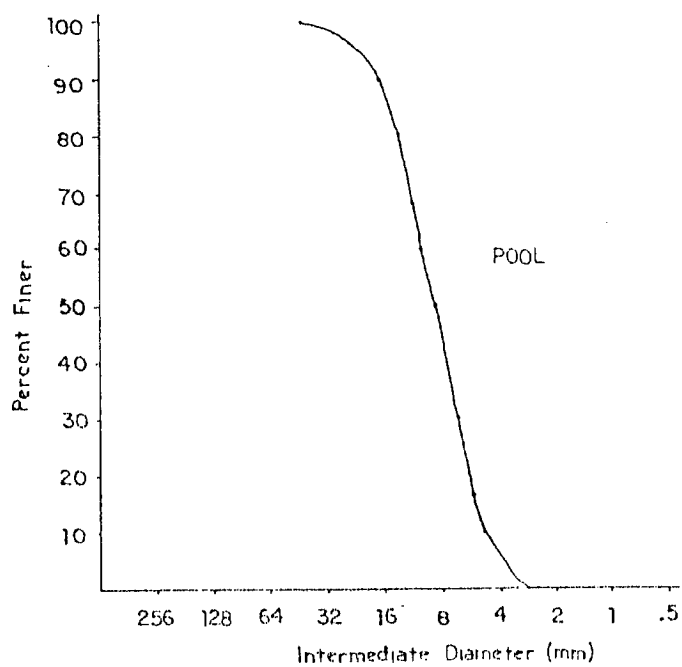


Fig. 8a. Grain size distribution at Sample Site 3.

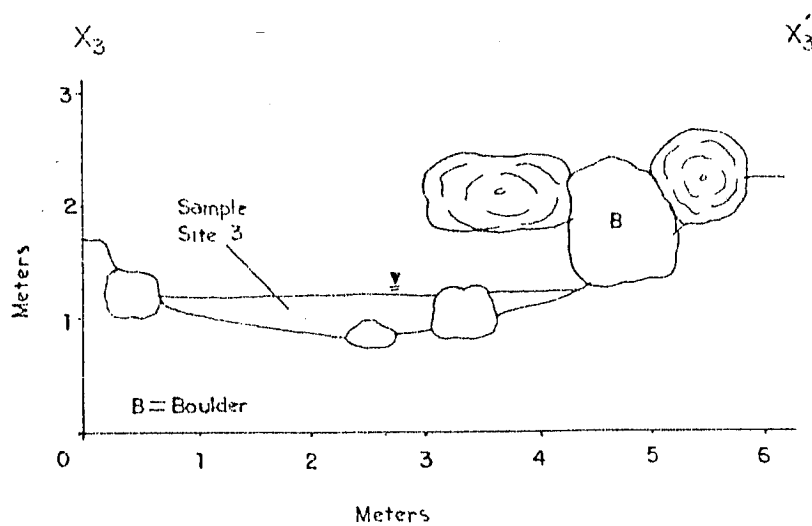


Fig. 8b. Cross section at Sample Site 3: Pool.

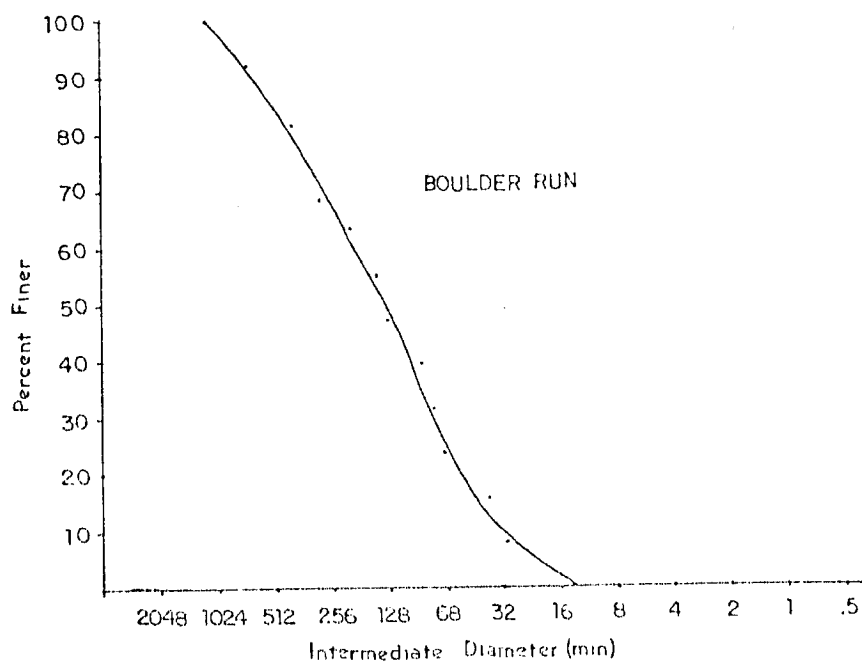


Fig. 9a. Grain size distribution at Sample Site 4.

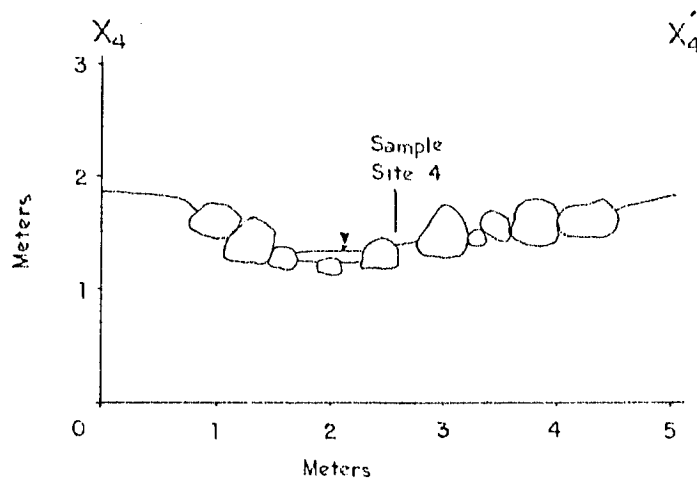


Fig. 9b. Cross section at Sample Site 4: Boulder Run.

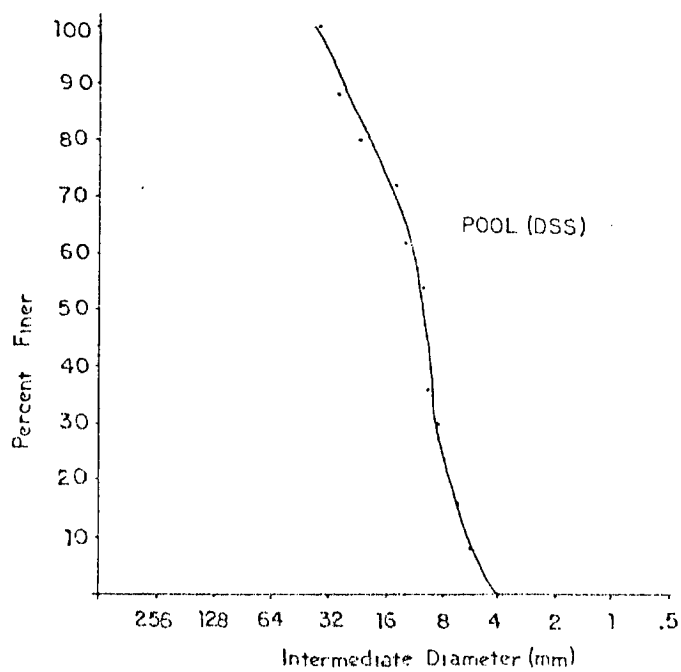


Fig. 10a. Grain size distribution at Sample Site 5.

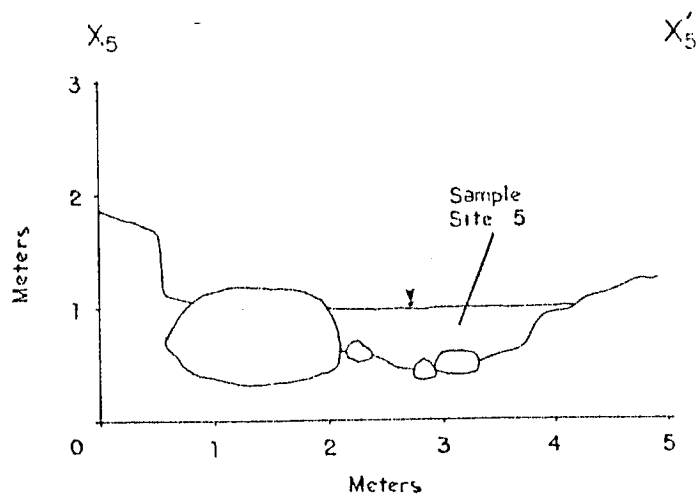


Fig. 10b. Cross section at Sample Site 5: Pool (DSS)

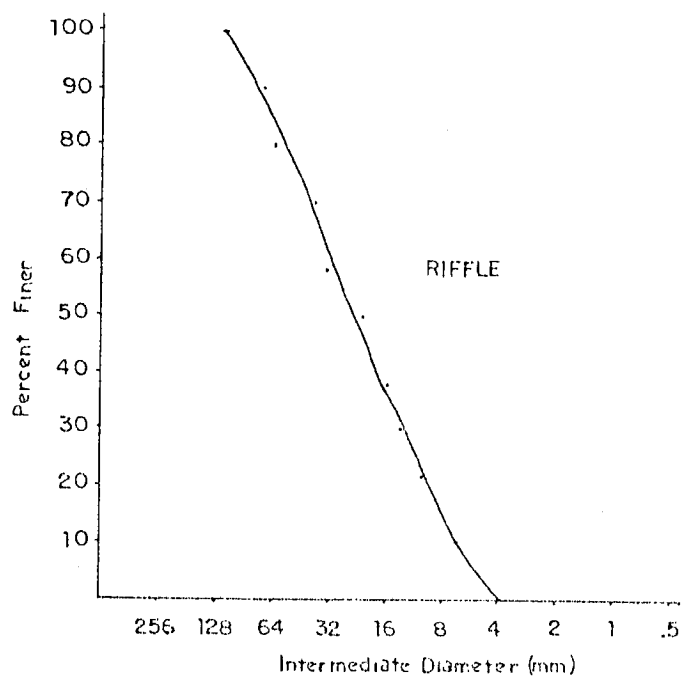


Fig. 11a. Grain size distribution at Sample Site 6.

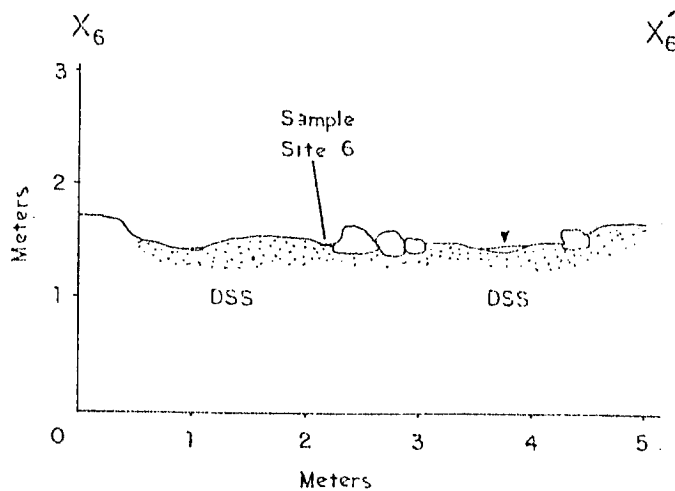


Fig. 11b. Cross section at Sample Site 6: Riffle.

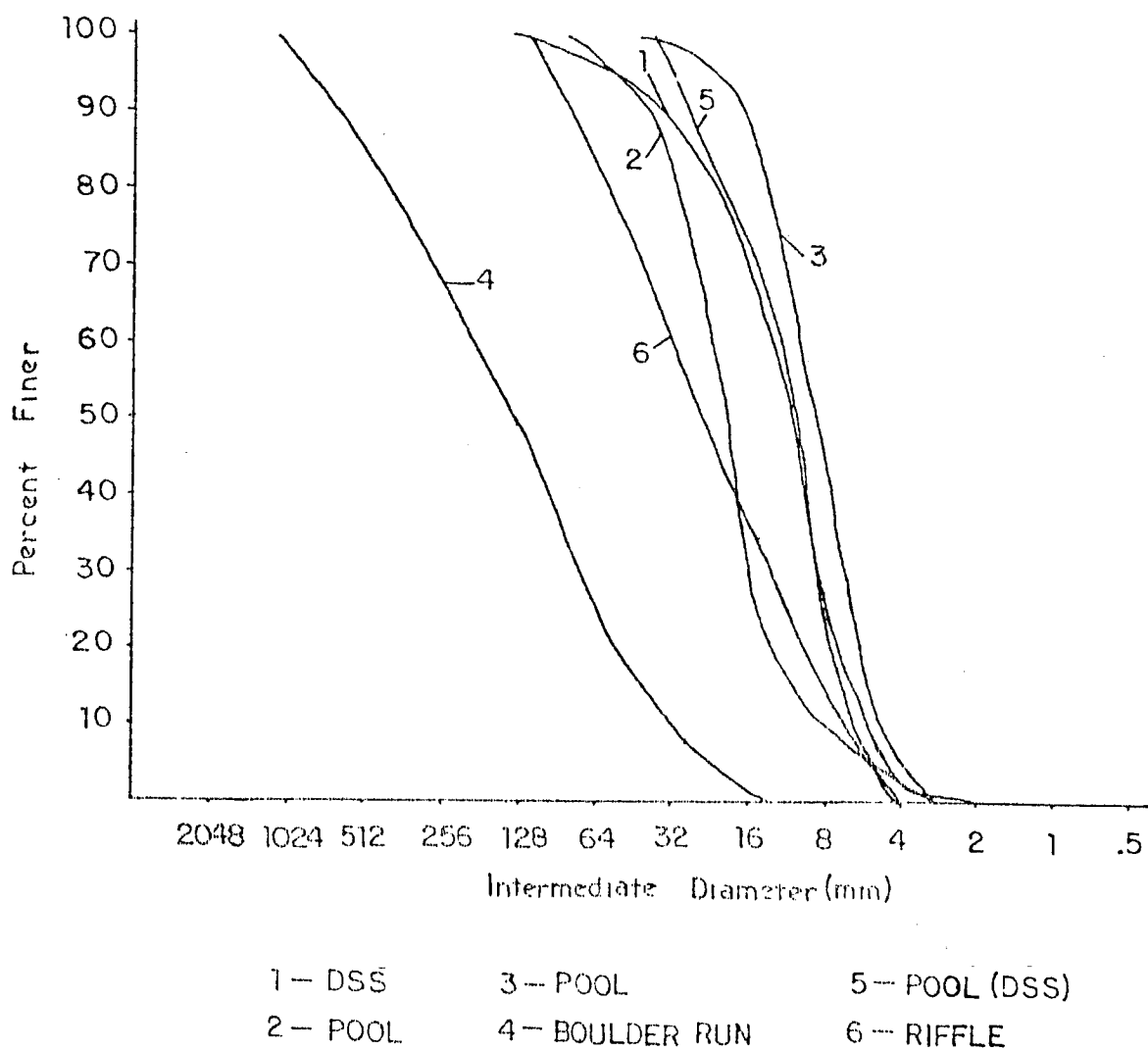


Fig. 12. Comparison of grain size distributions for Sample Sites 1-6. Note the fine grain size of the pools and DSS, and the coarser grain size of the riffle and boulder run.

form and process are significant in small to intermediate sized streams where a significant proportion of salmon and trout populations are produced.

After spending their adult life in the ocean, anadromous fish return to coastal freshwater streams to spawn. In order to facilitate the development of redds (nests dug by spawning fish into which the eggs are deposited) and the incubation of the eggs, spawning grounds must possess suitable gravel beds, a continuous supply of water, and protection from physical damage. Riffle areas within the stream environment offer excellent spawning grounds by providing coarser bed material into which redds can easily be developed, and through which intergranular flow of oxygen-rich water can more readily occur (Fig. 13). Debris dams provide temporary storage sites for

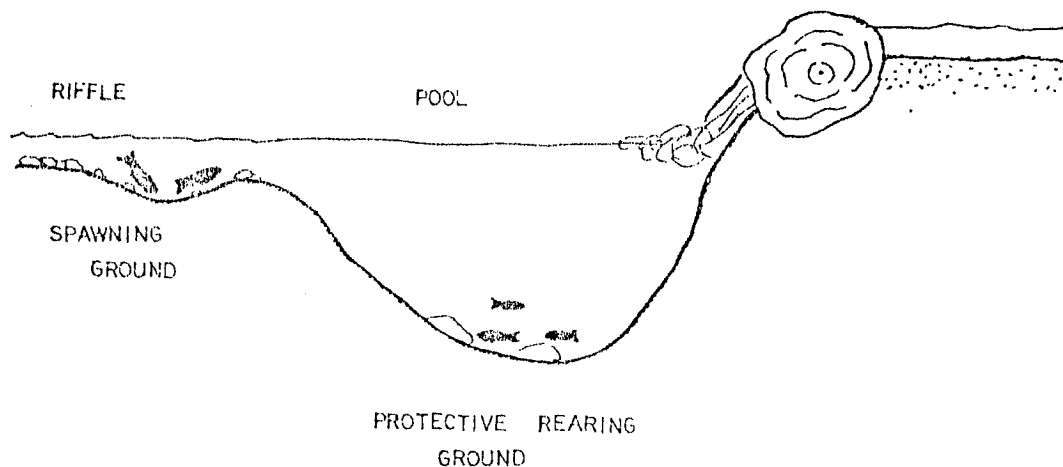


Fig. 13. Pool environments created or enhanced by large organic debris provide protective rearing grounds; and riffles, excellent spawning grounds for anadromous fish.

regulating sediment discharge, and thus may help to protect incubating eggs from being smothered by sediment, and to protect the fry from being restrained in emerging from the gravel (Meehan, 1974).

Young anadromous fish, after emergence from the redd, require rearing grounds with an abundant food supply, protective cover, and high water quality. Small organic debris (leaves, needles, twigs, bark, and cones) offers an immediate food supply, and large organic debris serves as a long-term food reserve and a stable substrate for insects upon which anadromous fish are dependent (Sedell and Triska, 1977). Furthermore, nutrients are supplied, and sediment levels are controlled by large organic debris, thus helping to maintain water quality. Large organic debris interacting with stream processes also provide a variety of habitats and flow conditions for the developing salmon and trout. In addition, riparian vegetation stabilizes undercut banks which provide protective areas for the young fish.

Timber harvesting practices have drastically reduced the quality of the stream environment and have had a negative net effect on anadromous fish. Removal of riparian vegetation eliminates shading of the stream environment, causing an increase in water temperature. Increases in temperature of only a few degrees can affect the duration and timing of incubation, can decrease the

dissolved oxygen content of the water, and can promote growth of fungi and slime bacteria which can smother the fish eggs (Meehan, 1974). Removal of the riparian vegetation also disrupts the food chain by eliminating the food base of the stream's biological community. A decrease in the number of protective undercut banks also results when the bank supporting vegetation is removed.

The removal of vegetation within the hillslope environment increases the chances of landsliding by increasing runoff, decreasing root strength, and transpiration. Disrupting of the protective duff layer and compaction of the soil during road construction, felling of trees, and yarding can increase soil erosion as well. Sedimentation of the stream channel due to high sediment inputs associated with soil erosion and landsliding can destroy much of the stream's fish habitat. Debris dams cannot adequately regulate these unnaturally high sediment loads resulting in the filling of pool habitats, and the destruction of gravel beds by the filling of intergranular pore spaces (Bjorn, T. C. and others, 1977).

The addition of large quantities of slash, logs, and other organic debris during logging can also have detrimental effects on stream quality and anadromous fish. Excessive amounts of organic debris can block fish runs, reduce the dissolved oxygen content of the water, and cause adverse channel erosion. On the other hand,

the previous discussion of large organic debris and channel form and process noted the benefits of having some large organic debris within the stream channel in order to maintain a healthy stream environment. These benefits were also noted in other studies (Meehan, 1974; Sedell and Triska, 1977; Keller and Tally, 1979; and Tally, MacDonald, and Keller, 1979). The limits at which organic debris is no longer beneficial, but detrimental, have yet to be defined.

Earlier studies have offered insight into the interactions between the hillslope, riparian, and stream environments, as well as interactions within the stream environment between large organic debris and fluvial processes. Findings from these earlier studies have led to changes in timber harvesting practices such as the use of buffer zones and stream clean-up following logging. These methods, however, must be executed correctly otherwise they will result in little or no benefits, and possibly even further damage. Erman, Newbold, and Rody, 1977, found from their evaluation of streamside bufferstrips that buffers greater than 30 meters retain the physical conditions of overhead canopy, channel stability, and invertebrate communities of unlogged streams. In contrast, streams with buffers less than 30 meters showed the same responses as streams logged without bufferstrips.

Stream clean-up began with the intention of removing the excess slash and debris deposited in streams during logging. It has been found that many times loggers remove natural debris as well. This is especially true in virgin forests where large old-growth trunks are removed by loggers because of their value as timber. This natural debris plays an important role in the development of a diverse habitat for anadromous and resident fish, and its removal could effectively channelize the stream (Swanson and Lienkaemper, 1978). This points out the need for a comprehensive timber harvest management program, and the inclusion of a follow-up plan to monitor its implementation.

CONCLUSIONS

1. The interactions between large organic debris and fluvial processes in old-growth, redwood environments is important with respect to the development and maintenance of a healthy stream environment and anadromous fish habitat.
2. Intermediate sized streams supply a significant percentage of anadromous fish population, such as steelhead trout and salmon, and are the most susceptible to stream temperature and fluctuations.
3. In steep, small to intermediate sized streams, landslides commonly occur due to the steep hillslope environments and lack of a distinct floodplain.

4. In small to intermediate sized streams slope and flow conditions are influenced by large organic debris. In Hayes Creek, 38% of the drop in slope is associated with organic debris; in Upper and Lower Little Lost Man, 59% and 30%, respectively.

5. In small to intermediate sized streams debris greatly influences the development of pool habitat--83% of the pools in Hayes Creek are associated with organic debris; 100% and 90% for Upper and Lower Little Lost Man.

6. In small to intermediate sized streams debris controls the sediment discharge by providing storage sites, thus maintaining riffle habitat for anadromous fish.

7. Timber harvesting has an adverse impact on hillslope, floodplain, and channel interactions, and interactions between large organic debris, and channel form and process.

8. A comprehensive, timber harvest management program should be developed, including subsequent monitoring. This is especially true for the sensitive environments of steep, small to intermediate forested streams.

TABLE 1
COMPARISON OF DEBRIS LOADING WITH UPSTREAM
DRAINAGE AREA, ORDER AND SLOPE

	Upstream Area (km ²)	Stream Order	Slope	Debris Loading (kg/m ²)
<u>Hayes Creek</u>	1.5	2	.12	170.0
<u>Little Lost</u>				
<u>Man Creek</u>				
Upper	3.5	2	.033	141.6
Lower	9.2	3	.048	49.0

TABLE 2
COMPARISON OF THE EFFECT OF ORGANIC
DEBRIS ON HAYES AND LITTLE LOST MAN
STREAM CHANNELS

	Pool Morphology Influenced by Debris (%)	Debris Controlled Drop in Elevation (%)	% Channel Area Undercut Banks	% Channel Area of Debris Stored Sediments	Upstream Drainage Area km ²	Stream Order
<u>Hayes Creek</u>	83	38	3.7	40	1.5	2
<u>Little Lost Man Creek</u>						
Upper	100	59	3	39	3.5	2
Lower	90	30	>1	39	9.10	3

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