

EFFECTS OF LARGE ORGANIC DEBRIS ON CHANNEL
FORM AND FLUVIAL PROCESSES IN THE
COASTAL REDWOOD ENVIRONMENT

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ABSTRACT

Large organic debris in streams flowing through old-growth redwood forests in California significantly influence channel form and fluvial processes in small to intermediate size streams. The role of large organic debris is especially important in controlling the development of the long profile and in producing a diversity of channel morphologies and sediment storage sites. The residence time for the debris in the channel may exceed 200 years.

The total debris loading along a particular channel reach represents a relation between rates of debris entering and leaving the reach. Loading is primarily a function of such interrelated variables as geology, valley-side slope, landslide activity, channel width, discharge, and upstream drainage area. Generally there is an inverse relationship between debris loading and stream size.

Large organic debris in steep mountain streams may produce a stepped-bed profile where a large portion of the stream's potential energy loss for a particular reach is expended over short falls or cascades produced by the debris. Approximately 60 % of the total drop in elevation over a several hundred meter second-order reach of Little Lost Man Creek is associated with large organic debris. The debris also provides numerous sites for sediment storage. Stored sediment covers up to about 40 % of the entire area of the active channel in the study sections. The sediment storage sites or compartments provide an important buffer system that regulates the bedload discharge.

The influence of large organic debris on channel form and process in low gradient stream reaches is less than in steeper channels. However, the debris still may affect development of pools and may help stabilize the channel banks. Root mats may armor banks and provide important fish habitats in the form of undercut banks. The stream channel of some low gradient reaches of Prairie Creek, California, may be quite stable. Lateral migration has only been one to two channel widths in the last several hundred years.

Management of streams in the coastal redwood environment so as to minimize adverse effects while maximizing anadromous fish habitat should consider the entire fluvial system. Managers should use natural stream processes to regulate channel conditions rather than strive for absolute control by artificial means.

INTRODUCTION

The virgin old-growth coastal redwood environment of Northern California is a unique forest system dominated by exceptionally large trees that grow to heights in excess of 100 m with diameters of several meters. They have an average life expectancy of about 1,000 yrs and may live more than 2,200 yrs (S.D. Veirs, 1978, personal communication). Even after death, large redwood trees resist decay and may remain on the forest floor or in stream channels for hundreds of years.

The range of ages of redwoods in old growth stands fits the concept of the "climax" forest. The density of trees in the studied area is approximately 50-125 trees per hectare, and the age distribution of the trees is uneven. Crown fires are rare because of the wet coastal climate, but surface fires have charred the bases of many trees. Mortality is dominantly a result of wind throw and landslides. The replacement rate for coastal redwoods is approximately 2-3 trees per 50 years per hectare (Veirs, 1978). This is a relatively low rate of reproduction compared to associated species in the forest such as Douglas fir, hemlock, spruce, and tan oak.

Large woody debris in the streams of the redwood forest can profoundly affect channel form and fluvial processes, particularly in small to intermediate sized streams. Old-growth forest along a small (first or second order) stream with abundant large organic debris is an exciting and aesthetically pleasing environment, providing a unique sense of permanency and perspective. In these small streams channel morphology is controlled by large (>10 cm in diameter) organic debris which is scattered where it fell in the channel. In larger (third and fourth order) streams the large organic debris tends to become concentrated in debris dams or jams that locally influence channel morphology and erosion-deposition patterns. However, the largest redwood debris (several meters in diameter) may remain where it fell for long periods of time. Large streams and rivers, such as Redwood Creek and the Klamath River, are capable of transporting even the largest redwood debris. Although it may be temporarily stored in mid- or side-channel bars, it is eventually transported to the sea. The influence of large organic debris on stream processes and form is thus most pronounced for small and intermediate sized streams. This generalization is consistent with studies in eastern hardwood or western Douglas fir forests (Keller and Swanson, in press).

The purpose of this paper is to discuss the role of large organic debris on channel form, fluvial processes, and development and maintenance of anadromous fish habitat for streams flowing through an old-growth redwood forest. Specifically we will consider: how the large organic debris affects channel width, depth, and slope; diversity of anadromous fish habitats such as pools, riffles and bars; areal sorting of bedload material; erosion-deposition patterns; and the instream residence time for large organic debris. We will

also make preliminary recommendations for management of anadromous fish habitat in the coastal redwood environment.

STUDY AREAS

The study area is located in the Redwood Creek drainage basin, approximately 70 km north of Eureka, California (fig. 1). Two streams of contrasting environment -- Prairie Creek, a low gradient meandering stream, and Little Lost Man Creek, a steep mountain stream -- were studied in detail during summer low-flow conditions. Procedures included measurement and/or development of channel profiles and cross-sections, morphologic maps, sediment size distributions, debris loading, and minimum residence time of large organic debris in the channels. Channel characteristics and data on debris loading for the five study reaches on Prairie Creek and Little Lost Man Creek are summarized in table 1.

Prairie Creek, along most of the three reaches studied, is entrenched several meters into conglomerates and sandstones of the Plio-Pleistocene Gold Bluff Formation. Some of the entrenchment may be due to recent and ongoing tectonic activity.

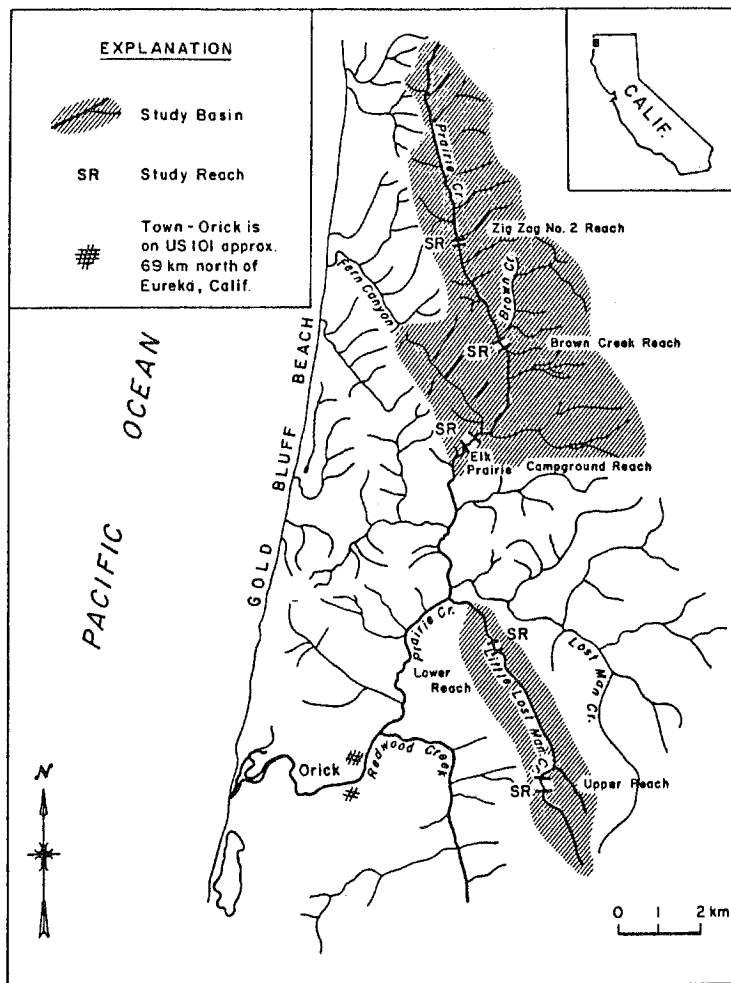


Figure 1. Index map of study areas.

Table 1

General Channel Characteristics for the Study Reaches of
Little Lost Man Creek and Prairie Creek

Reach	Thalweg Length (m)	Upstream area (km ²)	Stream Order	Channel Width (m)	Slope	Sinuosity	Debris Loading (kg/m ²)	Pool to Spacing (c)	% Channel area pool (e)	% Channel area rife area (e)	% Channel area stored sediment (e)	% Channel area under- cut bank (e)	Pool morph. influenced by debris (f)	% Debris con- trolled drop in elev. (g)
Little Lost Man Cr.														
Upper	270	1.1	2	6.4	.033	1.1	141.6	1.9 (d)	22	15	39	3	100	59
Lower	625	4.9	3	9.6	.048	1.1	49.0	1.8 (d)	18	21	39	< 1	90	30
Prairie Cr.														
Zig Zag No. 2)	220	5.7	2	6.7	.009	1.8	21.7	6.6	38	20	15	4	50	8
Brown Cr.	327	11.2	3	11.0	.010	1.2	84.8 (b)	6.0	26	18	29	< 1	67	18
Campground	447	19.8	4	18.5	.005	1.3	19.6	4.0	25	25	13	1	50	< 1

(a) Average width is the area of active channel divided by the reach length along the center line of the stream.

(b) Debris loading is calculated assuming density of wood averages 0.5 g/cm³. Debris loading is anomalously high for the Brown Creek reach. See text for explanation.

(c) Pool to pool spacing is measured in channel widths.

(d) Pool spacing in Little Lost Man Creek is due to spacing of large organic debris in the channel.

(e) Measured as percentage of total active channel area. Totals are less than 100 % because all stream environments are not included.

(f) Pools controlled or influenced by large organic debris as percentage of total number of pools in the study reach.

(g) Drop in elevation along the channel profile due to influence of large organic debris.

Little Lost Man Creek, a steep tributary of Prairie Creek, flows across steeply dipping sandstones, siltstones, shales and conglomerates of the Mesozoic Franciscan Formation. The local gradient of the stream is adjusted to the resistance of the various rock types.

LARGE ORGANIC DEBRIS: PROCESSES AND LOADING

The amount of large organic debris found in a channel reach is a function of the difference between the rate of debris entering the reach and that leaving. Large organic debris may enter a channel by landslides, blow-down of whole trees or portions of trees, bank erosion, and flotation of debris from upstream. Several of these processes may work in concert to deliver debris to stream channels. The dominant process depends upon local geologic conditions. For example, on steep sections of Little Lost Man Creek where the stream flows over resistant conglomerates and sandstone, the valley sides tend to be steep and landslides commonly deliver large organic debris to the channel. On the other hand, at locations where tributaries enter the stream, or along relatively low gradient sections where streamside trees are rooted in thick soils, undercutting of the stream banks may deliver most of the large organic debris to the channel.

Large organic debris, whether in the stream or on the banks, may be quite stable. For example, very large pieces of woody debris may be stabilized by having much of their mass resting out of the channel. Once in the channel, large organic debris may become stabilized by partial burial in sediment or by being wedged between other debris, boulders, or other obstructions. The debris may also be stabilized by the growth of nursed trees that send roots over the debris and into the soil, binding debris accumulations together.

Debris loading, for example the addition of one large root wad and trunk, may increase bank erosion which in turn is likely to undermine additional trees that subsequently will also fall into the channel. Furthermore, large debris in streams traps sediment and additional debris delivered from upstream by flotation (fig. 2). This process continues until the debris jam is removed by a combination of erosion, decay of supporting logs, and/or flotation during high flows.

Debris loading, measured in kilograms of vegetation per square meter of active channel (kg/m^2), was determined by measuring the length and diameter of all large organic debris with a diameter greater than 10 cm. Debris loading is calculated assuming the density of wood averages $0.5 \text{ gm}/\text{cm}^3$. This assumption facilitates comparison with other studies (e.g., Swanson and Lienkaemper, 1978; Keller and Swanson, in press) but may be questionable as the wet density of redwood may approach or even exceed $1.0 \text{ g}/\text{cm}^3$ (S.D. Veirs, 1978, personal communication). The value of $0.5 \text{ g}/\text{cm}^3$ is used cognizant of this limitation.

Because of the very large size of some redwood debris, a few large pieces may account for most of the debris loading in some reaches. For example, 60 % of the total loading along both the 400 m Upper Reach of Little Lost Man Creek and the 220 m Zig Zag No. 2 Reach of Prairie Creek consists of one redwood trunk (fig. 4 at DD6 and fig. 5 along sect. A-A').

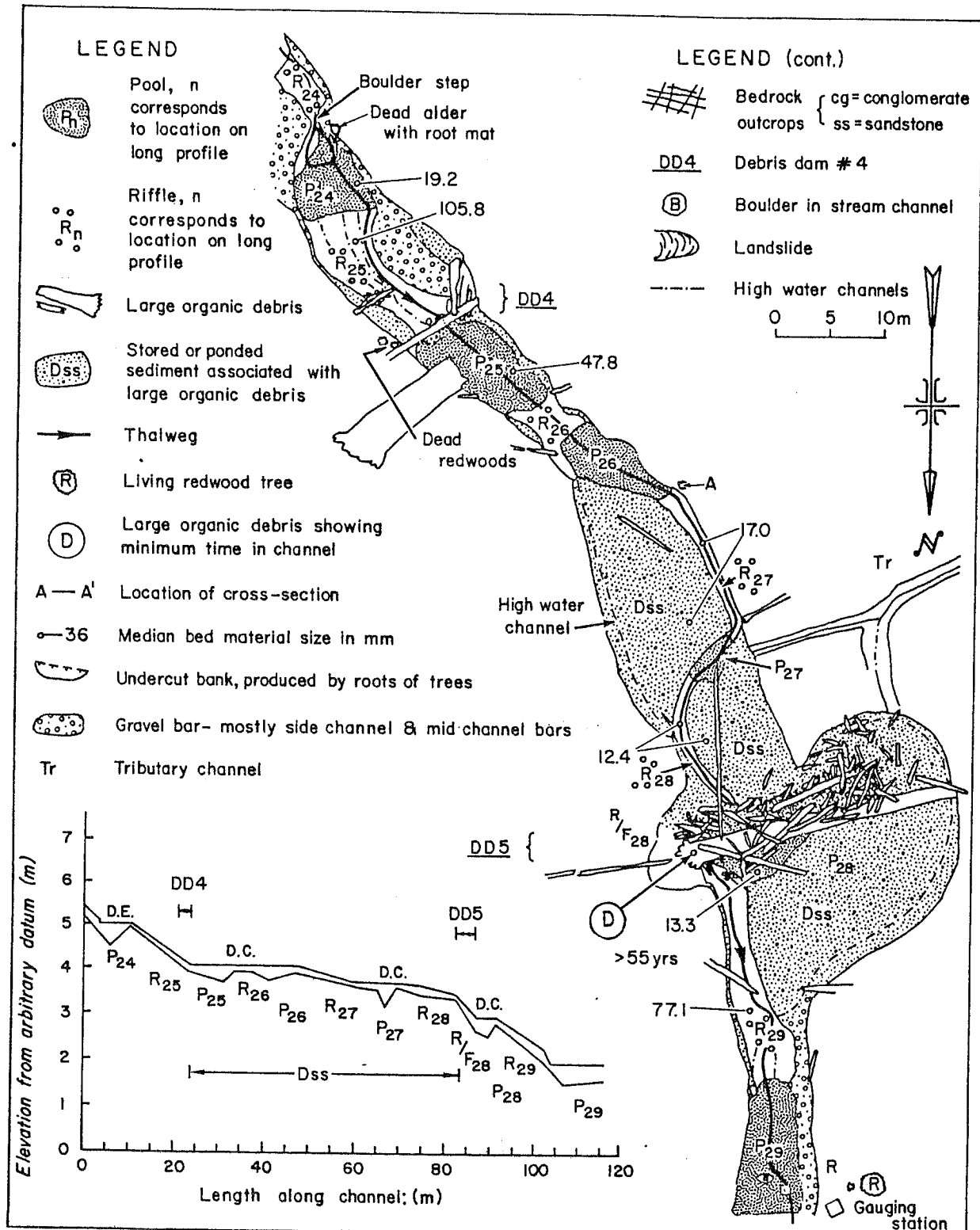


Figure 2. Morphologic map of a short section of the Lower Reach of Little Lost Man Creek. Notice the much wider channel at the site of debris dam (DD5), and the finer gravel which constitutes the debris-stored sediment. The location is downstream from the profile in figure 10. The symbol R/F indicates the location of a riffle-falls.

Redwood, Douglas fir, Sitka spruce, western hemlock, big-leaf maple and alder are the main contributors of large organic debris in the coastal redwood environment. However, because redwood debris tends to be very large and resistant to decay, it dominates the total loading.

Independent of other factors, in timber stands where all the trees are of about the same size, the debris loading should be greater in first and second order streams because the flow may not be able to float large debris. In larger streams, debris accumulates in distinct debris jams. With further increase in stream size, even the largest debris may be floated away. This is essentially the situation in Pacific Northwest streams that flow through Douglas fir forest (Swanson and Lienkaemper, 1978). In the coastal redwood environment, the situation is not entirely analogous because redwood debris occurs in a larger range of sizes. In spite of this, with the exception of the Brown Creek Reach of Prairie Creek, the general tendency of debris loading to decrease in the downstream direction as drainage area and channel width increase is apparent (table 1).

Debris loading in the study reaches of Prairie Creek varies from 19.6 to 84.8 kg/m². The highest measured loading occurs in the Brown Creek Reach and appears anomalously high when compared to the other two Prairie Creek reaches. Because most of the loading results from a few very large stems, perhaps the high loading represents a pocket of recurring blowdown. However, the origin of the high loading appears to be complex, involving several factors. Included is the long profile of Prairie Creek in the vicinity of the Brown Creek Reach. The profile is anomalous in that the study reach is located between two convex reaches along an otherwise uniform concave long profile (fig. 3). The origin of the convex reaches is not known but apparently is related to the geology and, hypothetically, to recent uplift. Admittedly evidence for uplift is weak in that it is based primarily on anomalous topography including: local trellis drainage patterns, possible stream capture, and several meters of entrenchment of Prairie Creek in the vicinity of the convex profile.

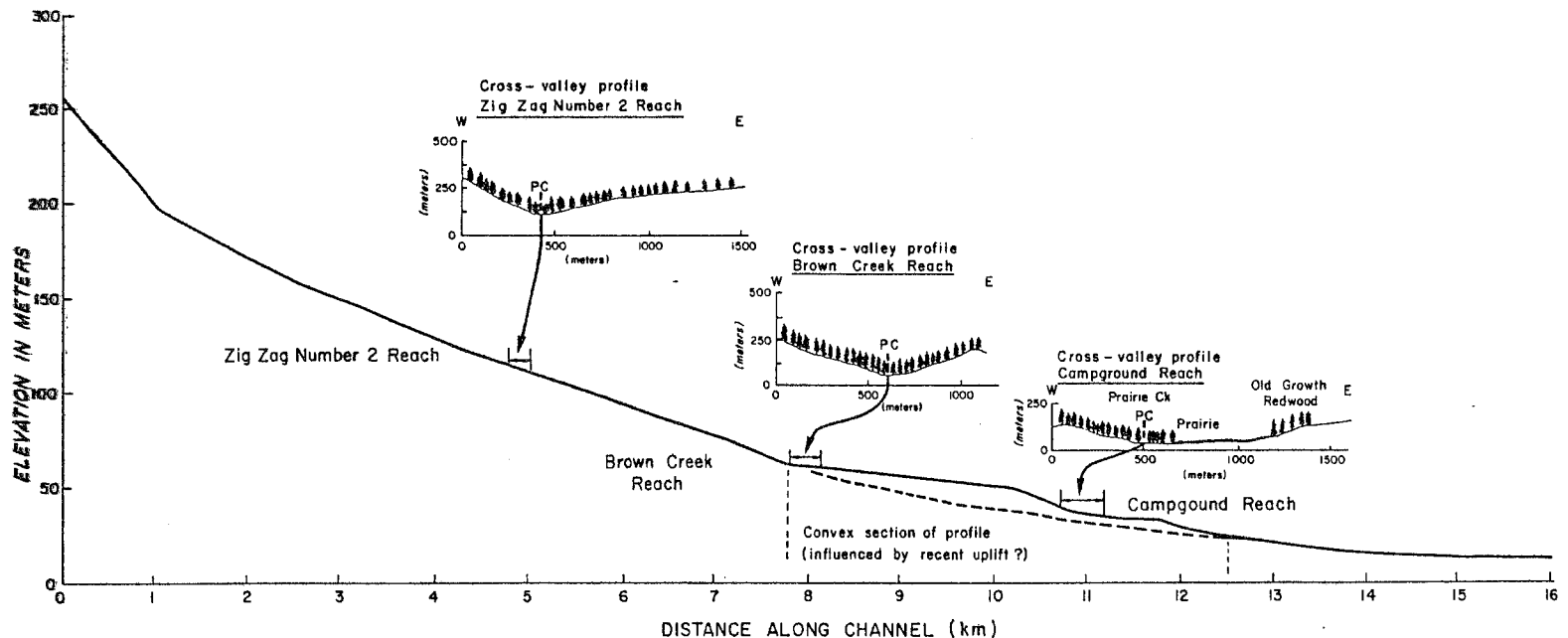


Figure 3. Long profile for Prairie Creek. Compiled from 1:24,000 scale topographic map.

Regardless of whether or not the entrenchment is due to recent tectonic activity, entrenchment influences debris loading by producing locally steep valley sides close to the channel. The cross-valley profiles of the three reaches (fig. 3) demonstrate that near Brown Creek the valley walls are steep and the valley width relatively narrow. Entrenchment is illustrated by the cross-channel profiles (fig. 8). The steep valley sides, more frequent entrance of tributary channels, and entrenchment increase the likelihood of large organic debris being delivered to the stream channel. Tributary junctions are especially significant because at these sites bank erosion acts along two fronts, thus increasing the prospects of a tree falling in the channel.

Measured debris loading in Little Lost Man Creek varies from 49 to 141.6 kg/m² (table 1). In the Lower Reach debris loading is lower. However, debris jams (or dams) are larger, more complex and spaced further apart than in the headwater areas (compare figs. 4 and 12 with figs. 13 and 14). A single large trunk generally supports the complex debris jams (see fig. 2, DD5 and fig. 4, DD3). Debris loading is locally higher along steep reaches where the frequency of landslides is relatively high (fig. 4).

Comparison of measured debris loading in Prairie Creek and Little Lost Man Creek with streams of similar size flowing through western Douglas fir forests shows interesting differences. For example, Mack Creek in the McKenzie River system, western Oregon, is a third-order stream with upstream drainage area of 6 km² and a channel width of 12 m; the debris loading is 28.5 kg/m² (Keller and Swanson, in press). By comparison the Lower Reach of Little Lost Man Creek, a third-order stream with upstream drainage area of 4.9 km² and a channel width of 9.6 m, has a debris loading of 49 kg/m². Furthermore, Devilsclub Creek and Watershed 2 Creek, also in the McKenzie River system, each with an upstream drainage area of less than 1 km², have debris loading of about 40 kg/m² (Keller and Swanson, in press). This is considerably less than the 141.6 kg/m² measured in the Upper Reach of Little Lost Man Creek, where the drainage area is 1.1 km². Debris loading in two other streams, Low Slope Schist Creek and Gans West Creek (both tributary to Redwood Creek) have also been measured. These small, steep streams, both with drainage area less than 1 km², flow through old-growth redwood forest and have debris loading of 51.9 kg/m² and 56.3 kg/m², respectively (F. Swanson, personal communication). These values are somewhat higher than the loading of small streams (for examples, Devilsclub and Watershed 2 Creeks) in the McKenzie River system flowing through western Douglas fir forest.

Additional data are needed before more meaningful comparisons of debris loading in streams flowing through different forest environments can be attempted. Nevertheless, the unusual size of the redwood debris demands that the general pattern of downstream decrease in debris loading be shifted downstream. Thus, in comparing two very similar second, third, or fourth order basins (one in redwood and the other in western Douglas fir forest), the debris loading at a particular location should be greater for the redwood basin.

CHANNEL FORM AND PROCESS

Large organic debris in forest streams may significantly influence channel form and fluvial process in small to intermediate size streams. This is especially true in the virgin coastal redwood environment where individual pieces

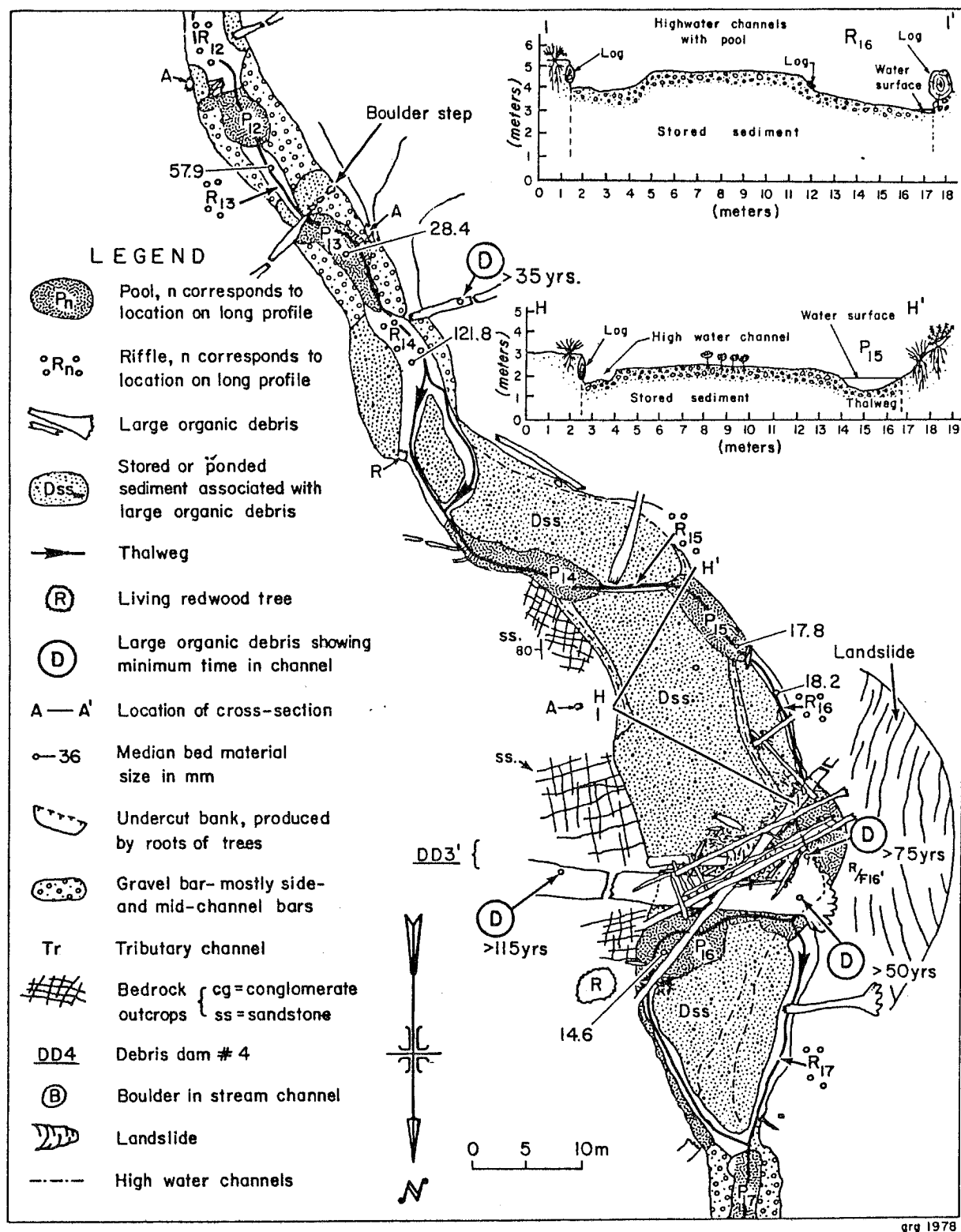


Figure 4. Morphologic map of part of the Little Lost Man Creek, Lower Reach. The location is shown on figures 1 and 10. The landslide probably started at least 75 yrs ago, which is the minimum residence time for the large redwood trunk (D7). The pool, riffle and debris dam numbers correspond to the long profile (fig. 10). The symbol R/F indicates the location of a riffle-falls.

of organic debris can be extremely large. For example, a stream with an active channel width of about 5 m may have one entire bank, for a distance of several channel widths, completely formed and defended by a single downed redwood tree (see fig. 5, sect. A-A'). The role of large organic debris is especially significant in development of long profiles and of diverse channel morphologies and sediment storage sites.

Slope

Channel slope, one of the major dependent variables in the fluvial system, is a function of several independent variables including peak and mean annual water and sediment discharges, topography, size of bed material, bedrock type, and recent tectonic activity. All these factors, and others, interact to produce the long profiles of rivers. Furthermore, the long profile is adjusted so that there is a compromise between least work and equal work (Leopold and Langbein, 1962). Because channel slope tends to adjust over a period of years (Mackin, 1948), the long profile reflects recent development of the stream channel on a variety of scales. The patterns of erosion and deposition, as well as the effects of bedrock geology on profile development were examined.

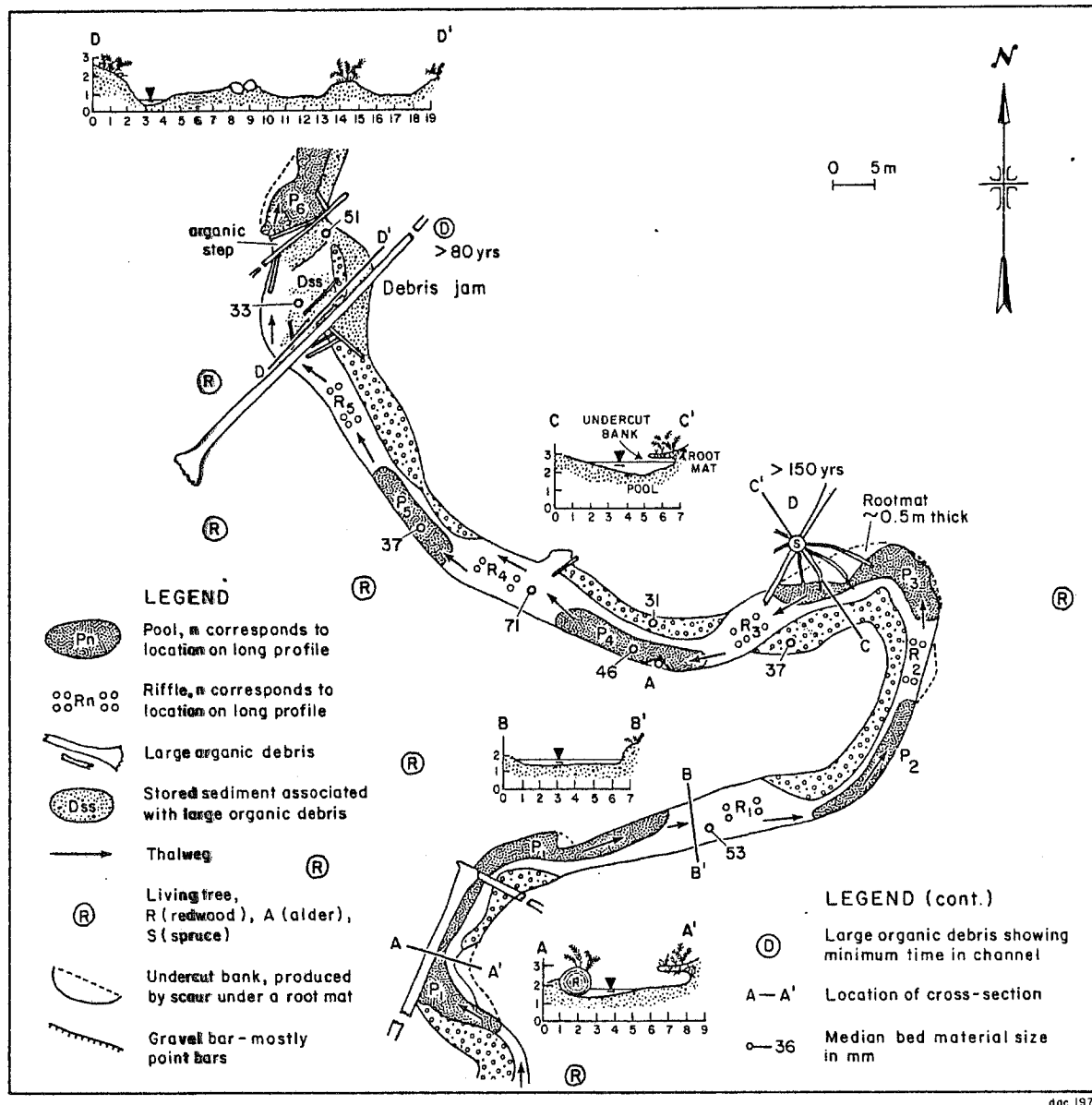
The effect of varying rock type on channel slope was investigated along Little Lost Man Creek, where several sedimentary rock types occur. The long profile extending from the headwater reaches to a point several kilometers downstream through old-growth redwood forest, was surveyed with a hand level and tape during the summer of 1978. Figure 6 shows a 500 m segment of this survey. The slope is steepest where the stream flows over conglomerate and massive sandstone, intermediate over thin-bedded sandstones, and relatively gentle over shale. Thus, the profile clearly shows that slope is adjusted to geology. These data (fig. 6) are consistent with the conclusions of Hack (1957) on relations between bedrock resistance and channel slope.

Also shown on this profile are effects of debris dams. A good deal of the total drop in elevation occurs at sites of debris dams. Extensive stored sediment occurs just upstream from the larger accumulations of large organic debris. However, debris dams on some steeper sections associated with conglomerate are less discrete and less involved with profile control than are dams on the softer sandstone and shale sections. Bed material is much larger where the slope is steeper, and much of the large organic debris remains above the active stream channel, resting on large boulders. Being above the channel, the debris does not exert significant control on the channel-forming process.

Steep gradient sections of Little Lost Man Creek often contain waterfalls of various sizes interspersed with riffles. These sections are termed riffle/falls and are noted as R/F on our maps and profiles. The pools on these steeper reaches often form as plunge pools below the waterfalls.

Channel Depth

Variable channel depth (and width) is particularly important in producing diverse habitats for anadromous fish (primarily steelhead and salmon) as well as trout. A goal of this study was to evaluate fish habitat and how it may be managed and improved.



dgc 1978

Figure 5. Morphologic map for Zig Zag No. 2 Reach of Prairie Creek. Notice the large redwood trunk defending the bank at A-A', and the considerable area of undercut banks. The location of this reach is shown in figure 1. The pool and riffle numbers correspond to the long profile (fig. 7).

Variation in channel depth is best analyzed on long profiles. Profiles of study reaches on Prairie Creek show well-developed pools and riffles (fig. 7). The upstream Zig Zag No. 2 reach has moderate debris loading (21.7 kg/m^2) and well-developed pools and riffles where large organic debris is locally very significant. At section A-A' in Zig Zag No. 2 Reach (fig. 5), the stream, for at least two channel widths, is defended by one large downed redwood tree. Undercut banks are common along this reach where the stream

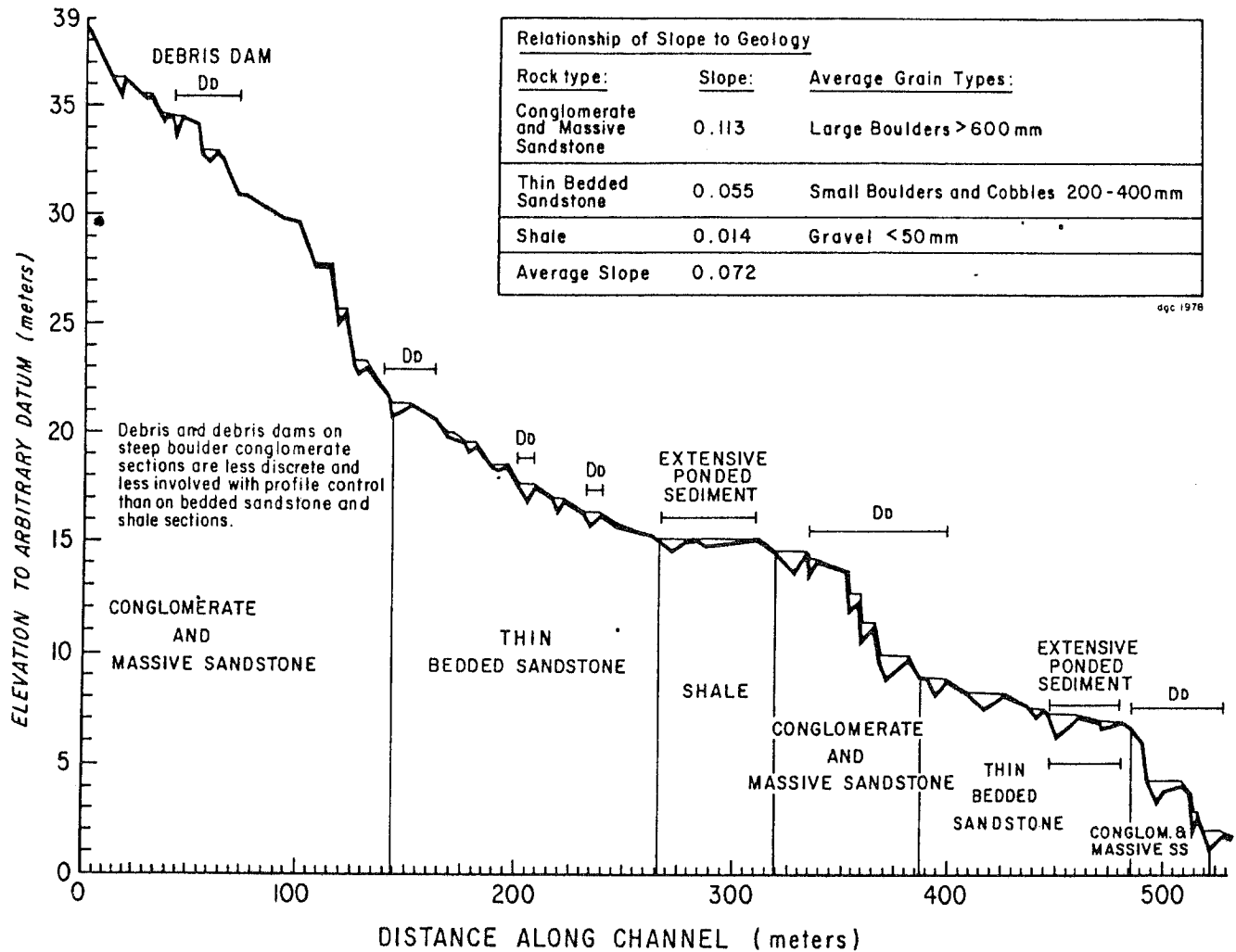


Figure 6. Illustration of relationship between geology, channel slope, and bed material size for a 500 m reach of Little Lost Man Creek.

scours beneath root mats. Undercut banks account for 4 % of the total channel area (table 1) and provide prime fish habitat. The Zig Zag No. 2 Reach has a relatively low gradient (0.009). Large organic debris account for only about 8 % of the drop in elevation along the 220 m reach. Nearly all of this is in one organic step at the downstream end of the reach. The phenomenon of organic stepping (Keller and Swanson, in press) is more important in relatively steep streams and will be discussed in the analysis of Little Lost Man Creek.

Figures 8 and 9 are morphologic maps along portions of the Brown Creek and Campground Reaches. These sites have well-developed pools and riffles. Particularly in the Brown Creek Reach, the organic debris loading is very high for Prairie Creek (84.8 kg/m²; table 1) and the debris tends to form distinct debris jams. Most of these jams have been formed by one or two large trees that trap other debris derived in part by flotation from upstream. The debris dams are clearly associated with and facilitate the formation of major pools along the Brown Creek Reach and thus are important in providing valuable fish habitat. For the Brown Creek Reach, the debris loading is relatively high (84.8 kg/m²), the major variations in depth of the channel are

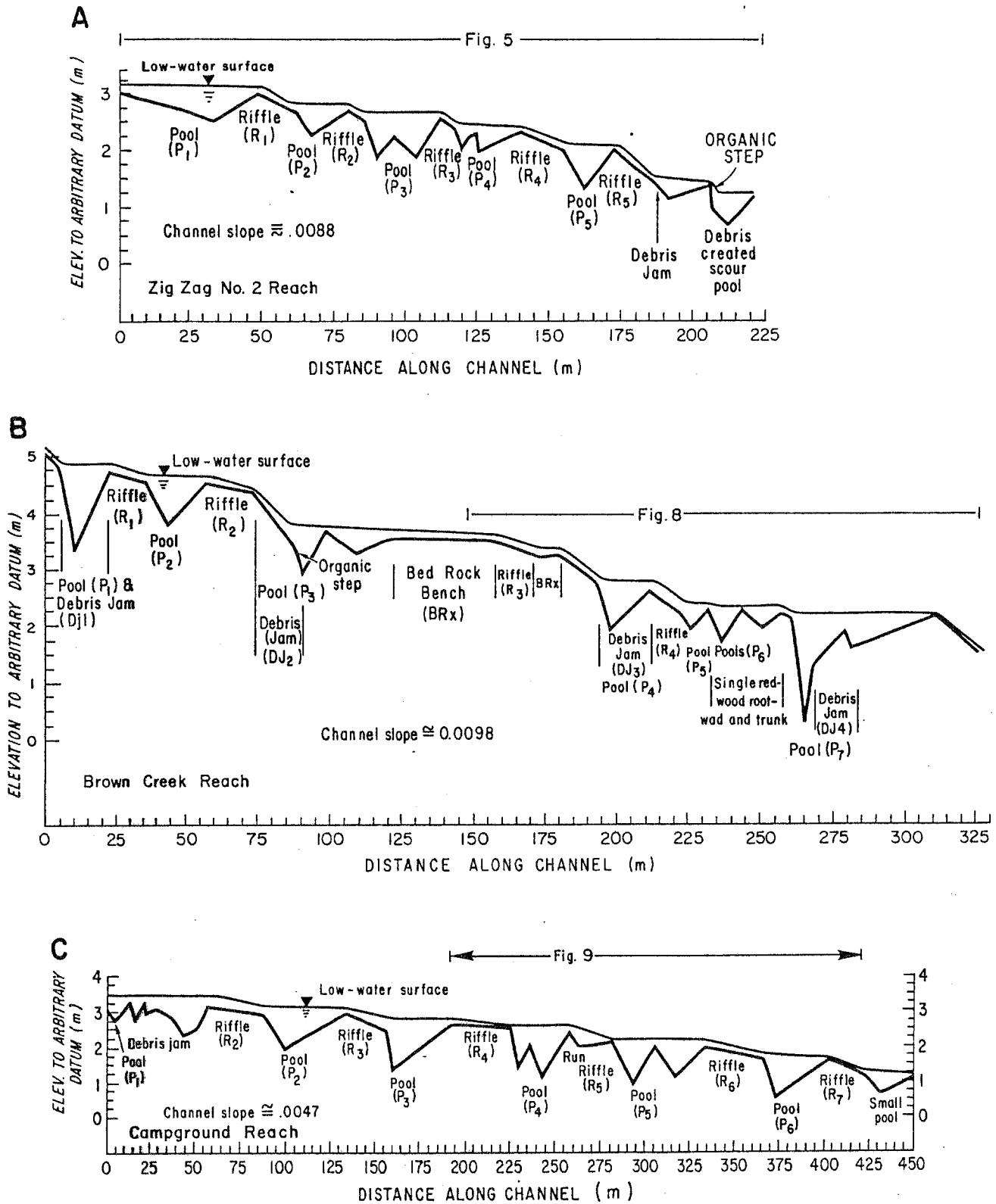
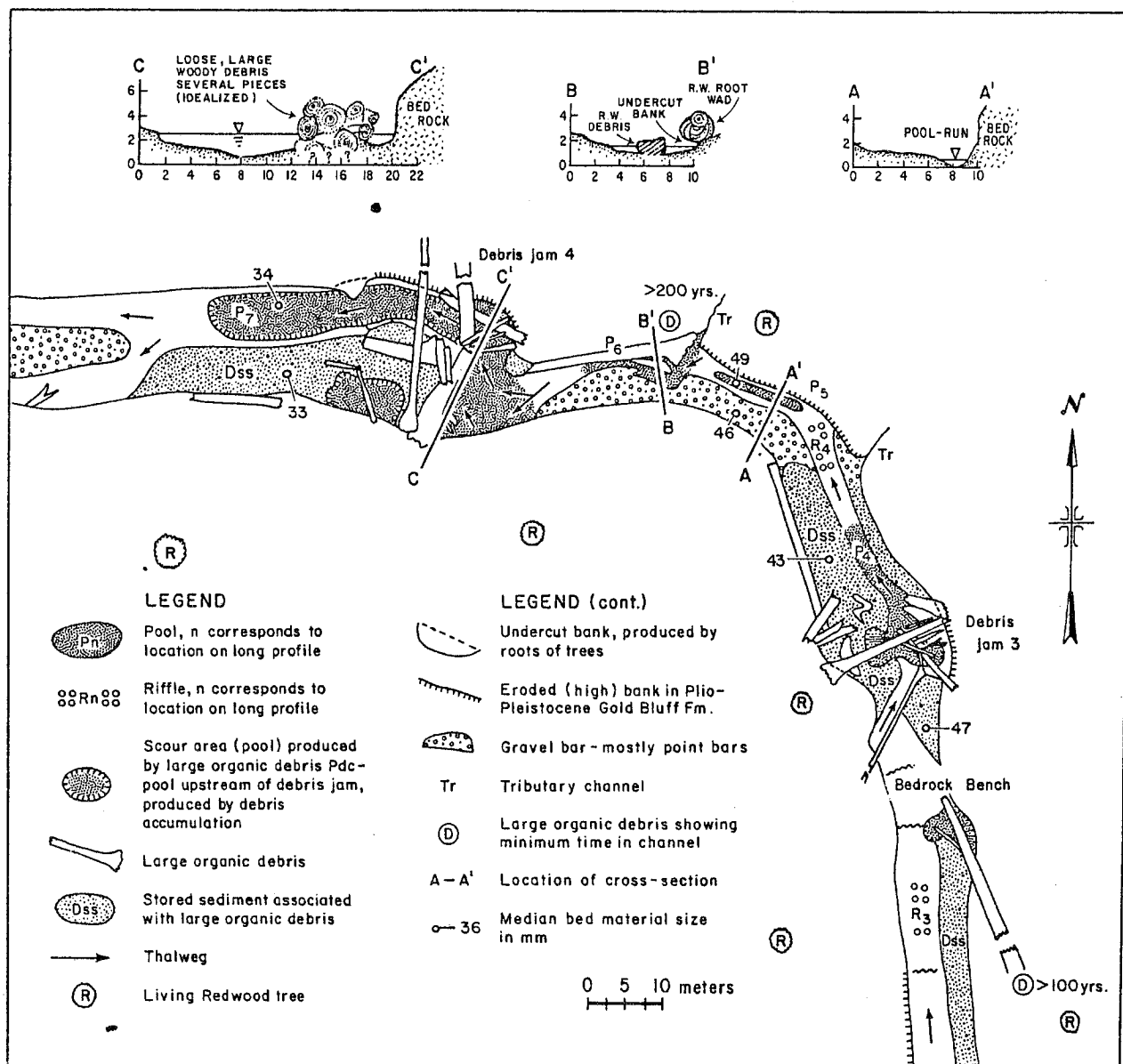


Figure 7. Long profiles for the three study reaches of Prairie Creek; (a) Zig Zag No. 2 Reach, (b) Brown Creek Reach, (c) Campground Reach. Locations are shown on figure 1.

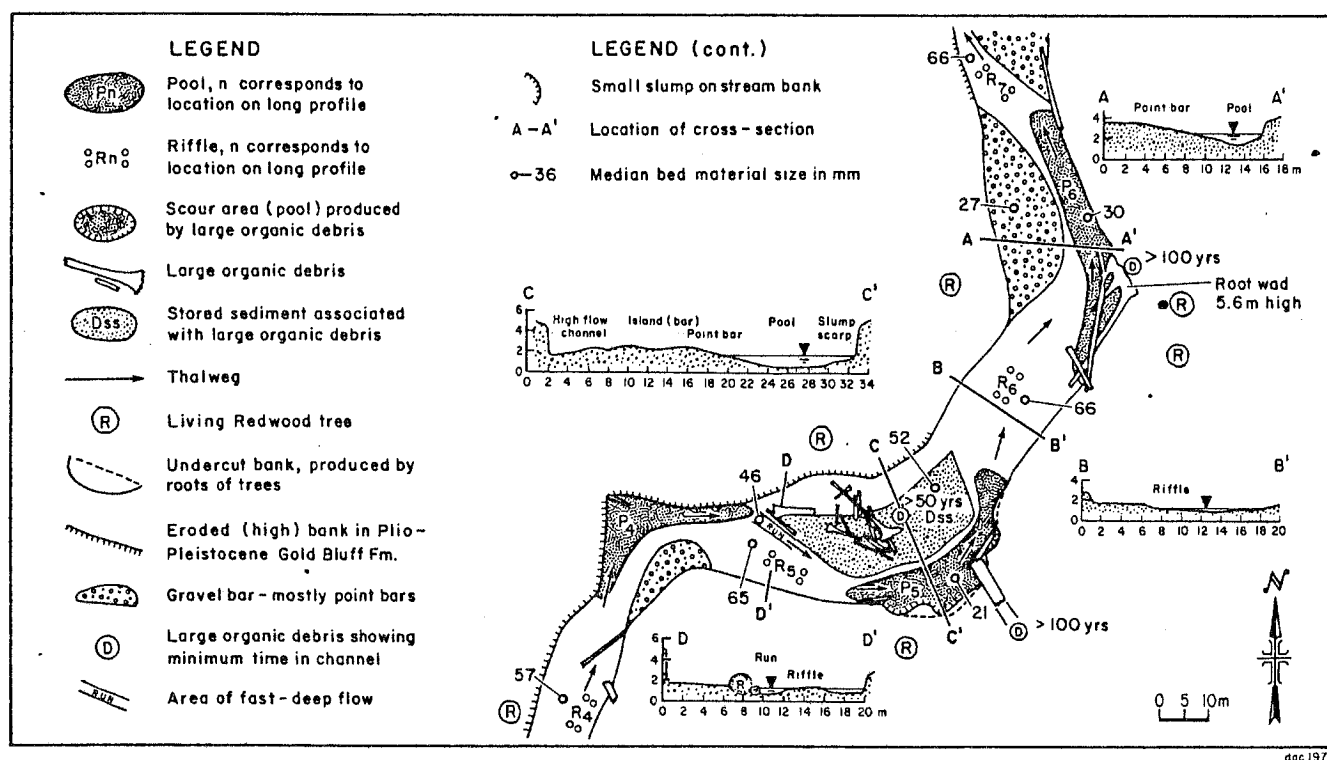


dgc 1978

Figure 8. Morphologic map of part of the Brown Creek Reach of Prairie Creek. Location is shown on figure 7. This reach shows distinct clumping of large organic debris and long residence time (>200 yrs) for one large redwood trunk and rootwad. The pool and riffle numbers correspond to the long profile (fig. 7).

directly associated with (if not caused by) large organic debris, and 18 % of the total drop in elevation of the 327 m reach is at sites where large organic debris has accumulated.

Only one debris jam occurs in the 447 m Campground reach along Prairie Creek (fig. 9), but most of the major pools are associated with some large debris. A very large redwood log evidently causes differential scour. In fact, many pools are associated with such large debris. A definite cause-



agc 1978

Figure 9. Morphologic map of part of the Campground Reach of Prairie Creek. Although debris loading is relatively low, large organic debris does significantly affect the development of channel forms such as pools. This site also has fairly good areal sorting of bedload material. Pool and riffle numbers correspond to the long profile (fig. 7).

effect relationship is difficult to demonstrate but the association is very strong. It is likely that large organic debris increases the variability of channel depth along the reach.

In Little Lost Man Creek the role of large organic debris in increasing the variability of channel depth is very pronounced. Figures 10 and 11 show profiles for the Upper and Lower Reaches and demonstrate some of the variability associated with large organic debris. In the Upper Reach the debris accumulations are discrete and more numerous. They provide many examples of organic stepping (Keller and Swanson, in press), which creates a variety of channel depths. Sediment is ponded above a debris dam and a pool is scoured immediately below the dam. The result of organic stepping is to produce a stream profile characterized by relatively long sections of stored sediment and low gradient alternating with short steep cascades or falls that terminate at a scour pool. The stepped profile is significant. Most of the downstream loss of potential energy takes place at the cascades or falls, thus reducing the energy available to erode the stream bed and banks. The pools provide temporary compartments for sediment storage. Furthermore, the steps produce a diversity of flow conditions and thereby create fish habitats (Swanson and Lienkaemper, 1978).

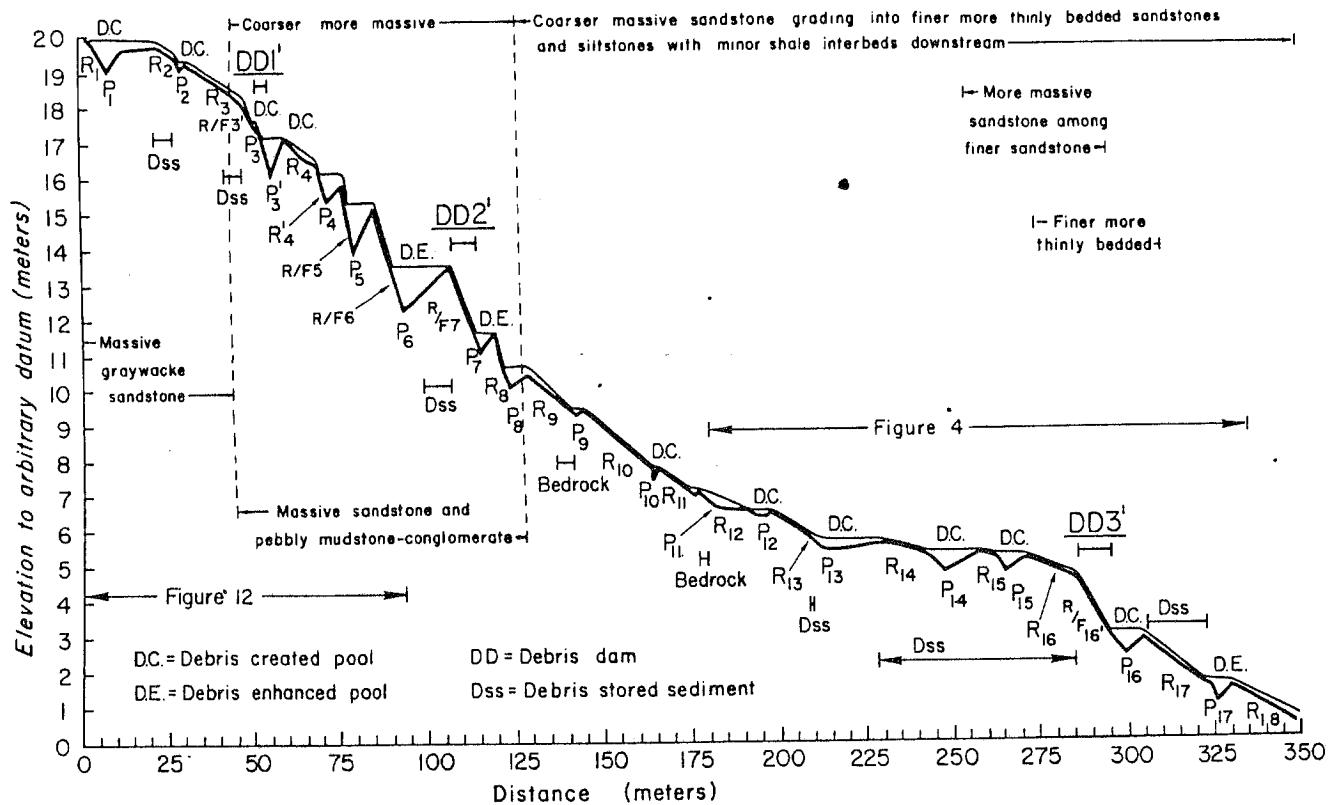


Figure 10. Long profile of the upper 60 % of the Little Lost Man Creek, Lower Reach (location shown on fig. 1). The slope here is 0.056 compared to an average slope of .048 for the entire reach. The pool, riffle and debris dam numbers correspond to morphologic maps (fig. 4 and 12). The symbol R/F indicates the location of a riffle-falls.

Channel Width

In some alluvial streams bankfull channel width is easy to define. However, in the coastal redwood environment trees and debris in the channel make it very difficult to define a characteristic channel width. In fact, the range of widths along a particular reach is often so great that one, or even several measurements, are nearly meaningless. Therefore, in this study the characteristic (average) width of active channel is defined as the area of active channel in a reach divided by channel length measured down the center line of the channel. The length of reach measured to calculate this width must be long enough to insure that several examples of various stream environments are included (pools, riffles, debris dams, etc.). Table 2 shows the variations of width for both Prairie Creek reaches and Little Lost Man reaches. With the exception of Brown Creek, the characteristic channel width is nearly the average of the channel width for riffles and pools (measured at their maximum width), exclusive of the debris dams. (Debris dams often have a channel width two or more times greater than the characteristic channel width.)

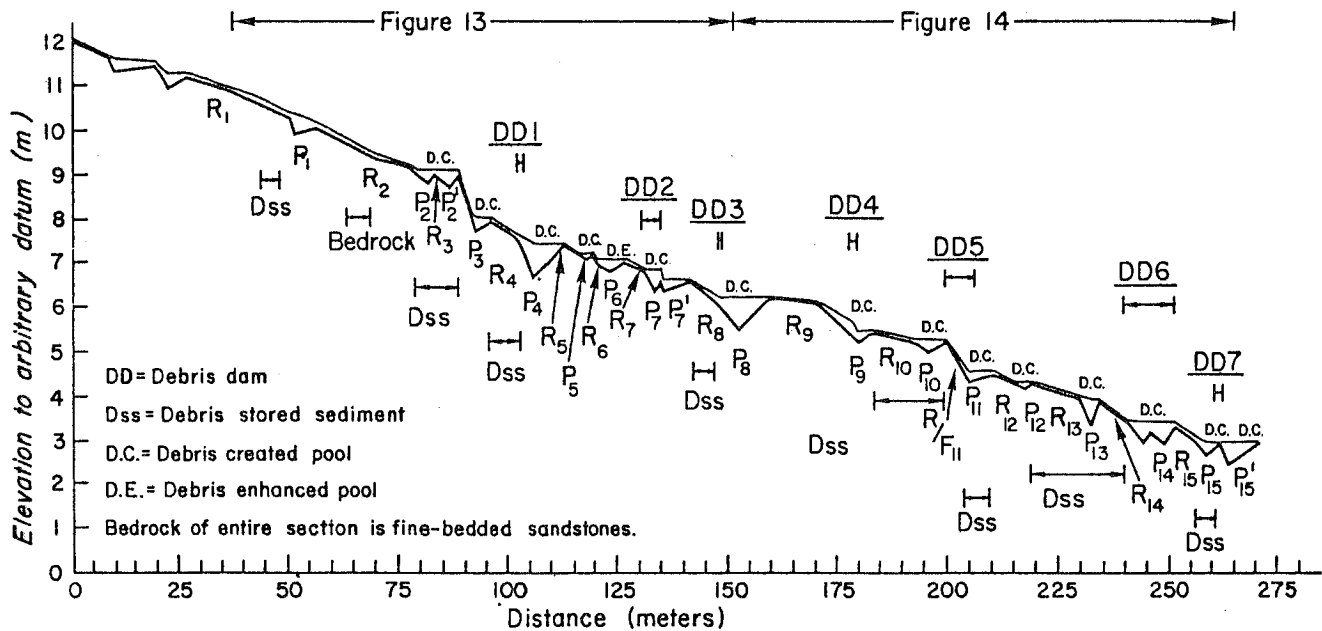


Figure 11. Long profile of the Little Lost Man Creek Upper Reach. The pool, riffle and debris dam numbers correspond to figures 13 and 14. Location of profile shown on figure 1. The symbol R/F indicates the location of a riffle-falls.

The configuration of a debris dam significantly affects both channel depth and width. Some debris dams consist of a single log while others contain several. Furthermore, some debris accumulations extend across the entire channel, whereas others do not. Simple debris jams are common in the Upper Reach of Little Lost Man Creek and many extend across the entire channel (figs. 13 and 14). In the Lower Reach the debris accumulations are large and only a few extend across the entire channel (figs. 2, 4, and 12).

Debris dams which extend across the entire channel in steep mountain streams usually cause horizontal divergence of flow away from the center of the channel. In turn this causes deposition of a mid-channel bar (stored sediment) upstream from the dam. The bar diverts the flow toward the sides of the channel, producing bank erosion and a locally wider channel. A plunge pool may form at the base of the debris dam (see fig. 2, DD5). In some instances debris dams that extend across the entire stream can also result in a more narrow channel width, by convergence of flow under the log (see fig. 13, DD1). This type of dam often produces sediment storage upstream and a well-developed scour pool downstream.

Debris dams that extend across only part of the channel are also quite common in Little Lost Man Creek. The dams divert the flow toward one bank which may cause bank erosion and a wide channel. This may also cause local scour (e.g., pool 5, fig. 13). In general these partial dams do not form the pronounced organic steps associated with the large debris dams that block the entire channel. However, they may influence the variability of channel width and depth for tens of meters both upstream and downstream from the dam.

Table 2
Comparison of Some Channel Widths for Pools, Riffles and Debris Jams

Reach	Upstream drainage area (km ²)	Characteristic width (a) (m)	Mean pool width (b) (m)	Mean riffle width (m)	Mean width debris jam (m)	Range of width (m)
<u>Little Lost Man Cr.</u>						
Upper	1.1	6.4	7.1	6.6	8.1	2.4-15.6
Lower	4.9	9.6	10.8	11.4	17.2	2.0-24.0
<u>Prairie Cr.</u>						
Zig Zag Nb. 2	5.7	6.7	7.3	5.6	15.0	3.0-15.0
Brown Cr.	11.2	11.0	7.0	8.3	16.1	6.5-20.0
Campground	19.8	18.5	20.1	16.0	25.5	10.0-31.0

(a) The characteristic (average) width is the area of the active channel in the study reach, divided by the channel length.

(b) The mean widths of the pools, riffles and debris jams are the average of the widths measured at the location of maximum width for each pool, riffle or debris jam.

Effects of Large Organic Debris

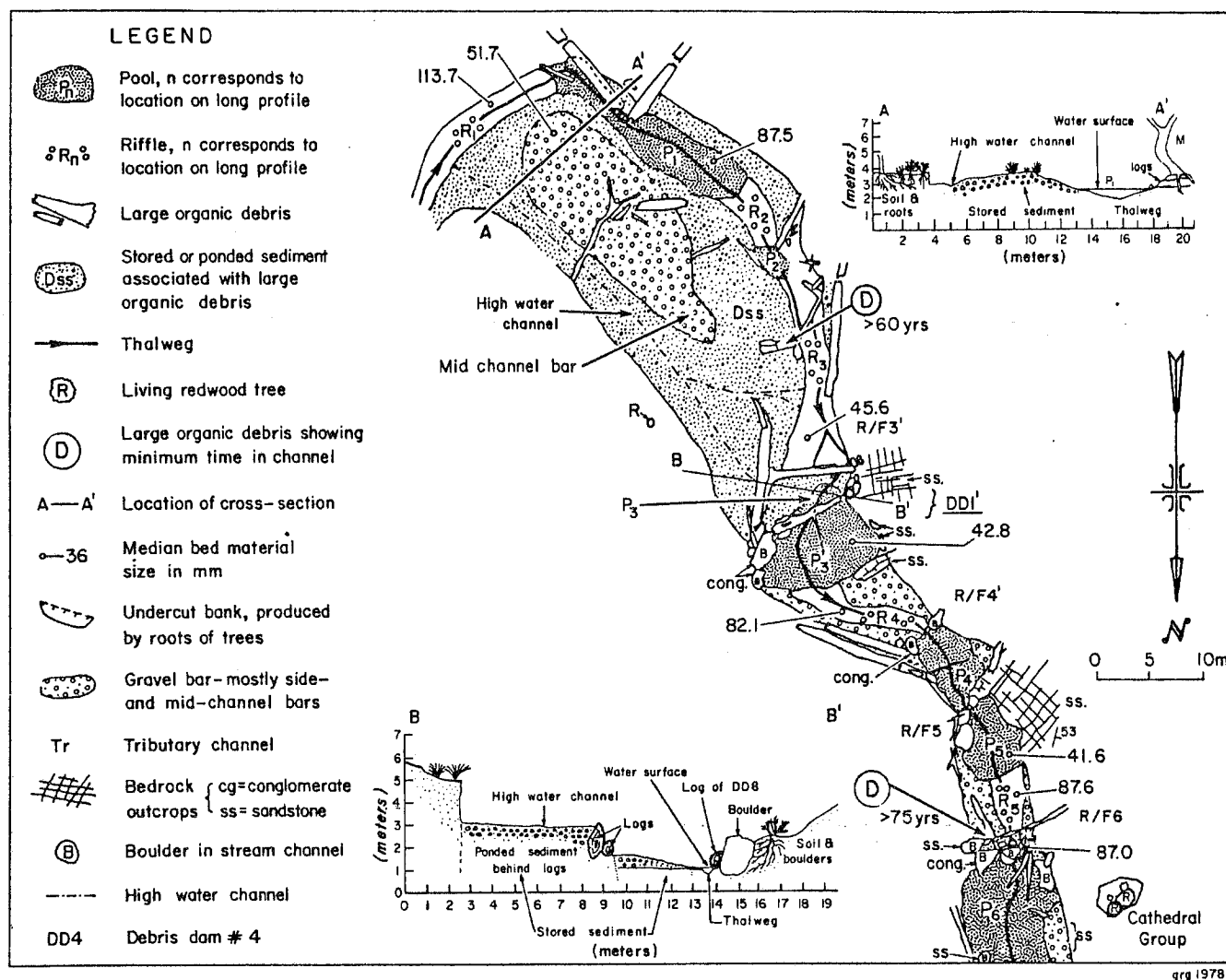


Figure 12. Morphologic map of part of the Little Lost Man Creek Lower Reach. Location on long profile and corresponding pool, riffle and debris dam numbers are on figure 10. The symbol R/F indicates the location of a riffle-falls.

Pools and Riffles

Observations of channel morphology were made at low water periods during summer. Little if any coarse bedload sediment is transported during these periods. Therefore observations were of channel features that developed in response to the higher flows during the winter months. Thus, the distribution of pools, riffles, and other channel features are, at times of low flow, relics of higher channel-forming stages.

Pools are topographic low areas of a channel produced by scour at higher flows. A variety of pools exists in the redwood coastal environment. Morphologic maps for Prairie Creek (figs. 5, 8, and 9) show locations of the major pools. In general, the spacing of pools varies from 4 to 6 channel widths, which is similar to the spacing of pools in other environments (Leopold and others, 1964; Keller, 1972). However, even in Prairie Creek there is consid-

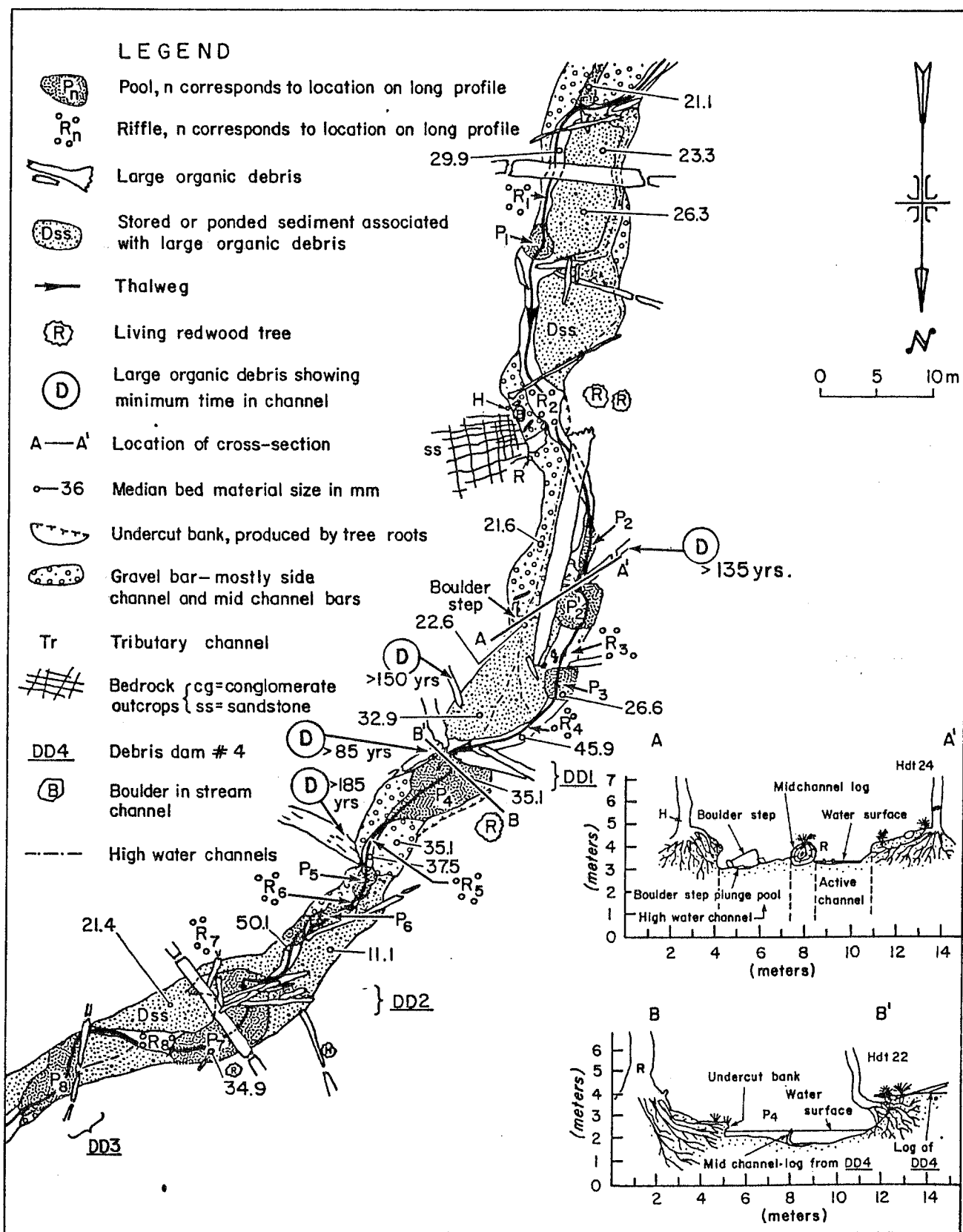


Figure 13. Morphologic map of part of the Little Lost Man Creek Upper Reach. Location of long profile and corresponding pool, riffle and debris dams are shown on figure 11.

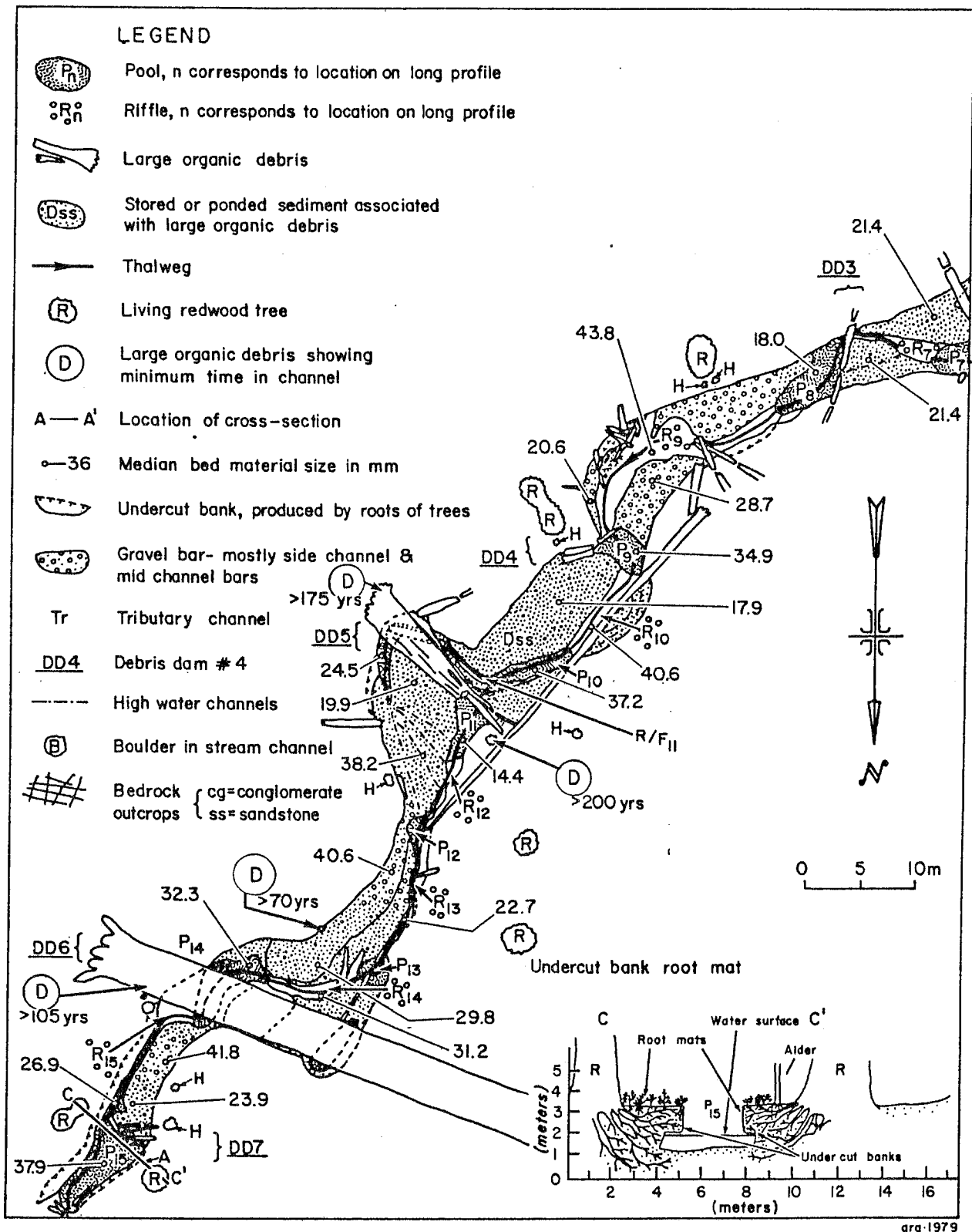


Figure 14. Morphologic map of part of the Little Lost Man Creek Upper Reach. Location of long profile and corresponding pool, riffle and debris dam are shown on figure 11. Notice that the large organic debris is scattered along the channel rather than in distinct clumps or groups. The symbol R/F indicates the location of a riffle-falls.

erable variability in the development of the pools, and at least 50 % of them are associated with large organic debris if not directly formed by it. The effects of large debris are particularly pronounced in the Brown Creek Reach where all the major pools are directly associated with debris accumulations which store large volumes of sediment. Debris-stored sediment accounts for nearly 30 % of the total area of the stream in the Brown Creek Reach.

In the steeper Little Lost Man Creek, pool development is more directly related to the large organic debris. In the Upper Reach of Little Lost Man Creek (figs. 13 and 14) approximately 60 % of the total drop is associated with debris accumulations, whereas in the Lower Reach (figs. 4 and 12), only about 30 % is associated with the debris. The average spacing of pools in Little Lost Man Creek is about two channel widths, reflecting the spacing of large organic debris. With the exception of the Brown Creek Reach, approximately 50 % of the pools in Prairie Creek are similar to pools observed in meandering alluvial streams lacking significant large organic debris. Those in Little Lost Man Creek, on the other hand, are more characteristic of the mountain streams described by Heede (1972) and Swanson and Lienkaemper (1978). In these small mountain streams organic stepping is fully developed and most significant in controlling local erosion and depositional patterns.

The pool environment is particularly important to fisheries resources because the deep water provides cover and living space for young developing fish. Pools that have undercut banks provide additional habitat for fish. In Prairie Creek some of the pools have undercut banks that extend several meters beneath root mats. The area in undercut bank amounts to as much as 4 % of the total area of active channel (0.28 m^2 per meter of channel) in the Zig Zag No. 2 Reach of Prairie Creek compared to 3 % (0.22 m^2 per meter of channel) in the Upper Reach of Little Lost Man Creek (table 1).

Riffles are topographic high areas in the channel produced at relatively high flow by deposition. Riffles are particularly important in fisheries resources because spawning occurs in these locations. The head of a riffle is critical in fish production because the intergranular flow of water is greatest at this location, and it provides oxygen-rich water to developing fish eggs. In the Prairie Creek study reaches, 18-25 % of the total channel area is covered by riffles, with pools covering another 25-38 %. In Little Lost Man Creek the riffle area is approximately 21 % and 18-22 % for pools (table 1).

Sorting of Bed Material

Patterns of sorting were studied at approximately 100 locations by sampling the bed materials according to methods outlined by Wolman (1954). In Prairie Creek the sorting of bed material is best in the lower reaches where the hydrology of the stream is less affected by the organic debris. Here the largest bed material is characteristically found on riffles and finer material is found in pools (fig. 9). In the Brown Creek Reach, bed material is not as well sorted. Apparently this is due to the fact that large organic debris produces greater variability of the flow. In Little Lost Man Creek the sorting of bed material is also variable but finer gravels tend to be associated with sites of debris-stored sediment (fig. 2).

Lateral Migration

Although Prairie Creek has a relatively low gradient with well-developed pools and riffles and numerous meander bends, preliminary analysis suggests that in several locations little lateral migration has occurred during the last several hundred years. This was determined by mapping the distribution of large living redwood trees near the channel. Ages of these trees were estimated by first counting the rings of three large downed trees to determine the diameter-age relation in the environment and then by using this relationship to estimate the ages of living trees from their diameters. The diameters and ages of the 3 downed trees are: 1.9 m, 568 yrs; 2.2 m, 898 yrs; and 2.8 m, 1006 yrs respectively. Therefore living trees with diameters of 3-5 m are probably 800-1000 yrs old. The location of these trees suggests that along several reaches the lateral migration of the stream has been only one or two channel widths in the last several hundred years. However, this conclusion is based on limited available data and thus is tenuous. Furthermore, the apparent stability does not suggest that there is no change in position of the channel with time. Meander cutoffs have occurred at several locations along Prairie Creek, but these appear to be fairly rare events. Only two or three abandoned channels were observed along Prairie Creek in the areas of old-growth redwood stand.

Thus although large debris greatly affects sediment storage and sites of erosion within the channel, the stability provided by living rootmats on banks and large organic debris in the channel may restrict the lateral migration of the stream. However, all large organic debris does not increase channel stability. Debris that blocks or diverts the stream may cause bank and bed erosion, whereas trees that fall in the down valley direction may defend a considerable length of channel.

Sediment Routing and Storage

Large organic debris is important in the routing and storage of sediment. Studies by Megahan and Nowlin (1976) and Swanson and Lienkaemper (1978) have shown that for their study areas annual sediment yields in small forested drainage basins are generally less than 10 % of the sediment stored in the channels. In the Brown Creek Reach of Prairie Creek, the area of debris-stored sediment is approximately 30 % of the total channel area, whereas in Little Lost Man Creek the area of debris-stored sediment amounts to approximately 40 % of the total channel area (table 1).

A major effect of the large organic debris on sediment routing seems to be that of a buffer (Swanson and Lienkaemper, 1978). This is sufficient in the coastal redwood environment, particularly in the small streams where large organic debris is scattered along the length of the channel. Mass wasting processes produce most stream sediment (Janda, 1977). Were it not for the storage sites provided by the debris, the sediment would be transported quickly from the small tributaries to larger channels downstream. Thus the role of the debris in these small basins is to provide temporary storage sites and thereby lessen the impact of mass wasting.

RESIDENCE TIME OF LARGE ORGANIC DEBRIS

Large organic debris moves through the fluvial system primarily by flotation at high flows or perhaps, in very steep sections of the stream, by debris torrents (Swanson and Lienkaemper, 1978). Because stands of old-growth redwood include trees of varying sizes and ages, their debris is moved through the system during flows of varying magnitude. Very large debris in Prairie Creek and Little Lost Man Creek moves only very rarely. This was determined from the storage period of large debris in the channel. When a large redwood tree falls, nursed trees such as hemlock, spruce, and other redwood trees soon begin to grow on the downed tree. Coring of nursed trees provides a minimum estimate of the time that the debris has been in a particular location.

Some of the ages derived in this manner are shown on the morphologic maps. Minimum residence time for 33 pieces of debris were determined. Only one is older than 200 yrs, but 17 are at least 100 yrs old (table 3).

Based on field observations of apparent residence times for fallen redwood trees, it appears that residence times of 500 yrs for large redwood debris in streams may be possible. Such potentially long residence times attest to the stability of the channel, which in turn is partly due to the large trees themselves. Of course, in the large streams, such as downstream reaches of Redwood Creek, there is sufficient water at high flow to float even the largest debris, so the residence time is shorter. Therefore, in these large streams, the role of large organic debris in influencing channel form and process is less than for smaller streams.

MANAGEMENT OF LARGE ORGANIC DEBRIS (PRELIMINARY STATEMENT)

Studies in Prairie Creek and Little Lost Man Creek are increasing our knowledge of the fluvial system in the coastal redwood environment. However, much remains to be done before comprehensive management criteria can be developed. Comprehensive studies by Janda (1977) in the Redwood Creek drainage established that the basin has been severely affected by clearcut logging. The logging is often associated with a greatly increased sediment load. Furthermore, loggers sometimes remove usable large redwood debris from stream channels. Therefore, stream basins that have been logged recently often have anomalously high sediment loads. Downstream channel aggradation is common and may result in bank erosion, producing a positive feedback that causes landslides. Thus still more material enters the stream channel. Sediment pollution and subsequent loss of habitat diversity in the channel have adversely affected anadromous fish populations.

Large organic debris in streams is sometimes assumed to be undesirable because it may block migration of fish and cause adverse channel erosion. In some cases this is true, but within limits large organic debris probably is necessary for a healthy stream environment (Sheridan, 1969; Meehan, 1974; Sedell and Triska, 1977; and Swanson and Lienkaemper, 1978). Debris helps produce diverse flow conditions that create a variety of stream habitats necessary for fish and other aquatic life.

How much large organic debris is necessary to produce the desired habitat? Stream cleanup operations may be "over zealous" in removing valuable

Effects of Large Organic Debris

Table 3

Minimum Ages for Large Organic Debris in the

Study Reaches of Little Lost Man

Creek and Prairie Creek

Reach	Tree Type	Age (yrs)	Location/ Association	Environment
<u>Little Lost Man Creek</u>				
Upper	Hemlock	130	Not Shown	Partial D.D. ^(c) /B.D.Tr. ^(d)
	Hemlock	135	Fig. 13, P 2 ^(a)	Partial D.D./B.D.Tr.
	Hemlock	150	Fig. 13, R 4 ^(a)	B.D.Tr. on Debris Stored Sed. ^(e)
	Hemlock	85	Fig. 13, P 4	D.D. ^(e)
	Hemlock	185	Fig. 13, P 5	Partial D.D./B.D.Tr.
	Hemlock	175	Fig. 14, P 11	D.D.
	Hemlock	200	Fig. 14, P 11	D.D.
	Hemlock	70	Fig. 14, P 13	M.C.B. ^(f) behind D.D.
	Hemlock	105	Fig. 14, P 14	D.D.
	Alder	60	Fig. 12, R 3	M.C.B. behind D.D.
	Redwood	75	Fig. 12, R/F ^(b) 6	Log over stream
	Redwood	220	Not Shown	B.D.Tr. downed trunk
Lower	Redwood	100	Not Shown	D.D.
	Redwood	80	Not Shown	Partial D.D.
	Alder	70	Not Shown	M.C.B.
	Sitka Spruce	22	Not Shown	Partial D.D./B.D.Tr.
	Sitka Spruce	35	Fig. 4, R 14	B.D.Tr.
	Sitka Spruce	115	Fig. 4, P 16	D.D.
	Redwood	75	Fig. 4, P 16	D.D.
	Redwood	50	Fig. 4, P 16	D.D.
	Sitka Spruce	65	Not Shown	D.D.
	Sitka Spruce	40	Not Shown	B.D.Tr. downed trunk
	Hemlock	20	Not Shown	B.D.Tr. downed trunk
	Redwood	55	Fig. 2, P 28	D.D.
<u>Prairie Creek</u>				
Zig Zag No. 2	Sitka Spruce	150	Fig. 5, P 3	B.D.Tr. with root mat
	Maple	80	Fig. 5, P 6	D.D.
Brown Creek	Redwood	160	Not Shown	D.D.
	Hemlock	100	Not Shown	D.D.
	Hemlock	100	Fig. 8, Side P	Partial D.D.
	Redwood	200	Fig. 8, P 6	B.D.Tr. downed trunk
Campground	Redwood	50	Fig. 9, P 5	M.C.B. after D.D.
	Redwood	100	Fig. 9, P 5	Partial D.D.
	Hemlock	100	Fig. 9, P 6	B.D.Tr. with root mat

Table 3 (continued)

(a) P = pool; R = riffle	(d) B.D.Tr. = bank defending tree
(b) R/F = riffle with falls	(e) D.D. = debris blocking entire channel
(c) Partial D.D. = debris dam blocking part of channel	(f) M.C.B. = midchannel bar

components of debris necessary for fish habitat (Swanson and Lienkaemper, 1978). The problem of too much large organic debris is likely to be encountered along streams that have been logged recently. Management of streams in areas previously logged may well involve removal of organic debris where it impedes or reduces the fish habitat. Or it may require placing a certain amount of large debris in other areas to help produce the desired habitat.

The best management procedures, from a philosophical standpoint, are those which utilize natural fluvial processes rather than traditional engineering approaches. The natural fluvial system must be worked with, rather than absolutely controlled.

A management program for small and intermediate size streams in the redwood coastal environment must necessarily involve a two-pronged attack. Consideration must be given to streams that have been logged and guidelines must be provided for future logging operations in virgin and second-growth timber. Management of streams affected by logging will be difficult. These streams, unless they have recovered morphologically, are seeking a new equilibrium in response to increased sediment and debris loads. The best approach might be to utilize sound conservation practices to reduce sediment production. The first concern should be the slopes adjacent to the streams. (This is essentially at the heart of the restoration work now being undertaken in the Redwood National Park.) After the sediment load has been reduced and the morphology of the streams is adjusted to the sediment load, stream habitats may be improved. The improvement can be achieved by (a) carefully evaluating the debris present and (b) adjusting debris loading to that expected under natural conditions.

Management of streams likely to be impacted by future logging must consider the possibility and likelihood of increased debris loading and sediment input as a result of the logging operations. This is just as important for streams flowing through advanced second-growth redwood stands as for old-growth, most of which is already logged. Greatest concern is with direct input of debris during logging, construction, and subsequent mass movement following logging. In most cases natural debris in the channels must be left in an undisturbed state, and steps should be taken to minimize the introduction of additional debris. It is assumed that logging regulations will continue to require a buffer strip along the stream. This should help minimize the impact of the logging on the stream. Lastly, conservation methods must be employed to minimize the occurrence of landslides and other mass wasting events. Each of these suggestions is aimed toward allowing the stream to exist in as natural an environment as possible. Even with this, logging in the vicinity of a stream channel is bound to disturb the fluvial system, but hopefully the effects can be minimized.

CONCLUSIONS

1. In the old-growth, redwood environment, the role of large organic debris is of primary importance in the development and maintenance of anadromous fish habitat in small and intermediate sized streams.
2. In Prairie Creek, at least 50 % of the pools in the low gradient study reaches are controlled or influenced by large organic debris. In the steeper reaches of Little Lost Man Creek more than 90 % of the pools are controlled by large organic debris.
3. Measured debris loading in kilograms per square meter of active channel varies from 19.6 - 84.8 kg/m² in Prairie Creek and 49 - 141.6 kg/m² in Little Lost Man Creek. These values are somewhat higher than those for streams of similar size flowing through western Douglas fir forest.
4. Generally there is an inverse relation between stream size and debris loading because small streams tend to have narrow valleys, steep valley slopes, relatively high frequency of landslides, narrow channels and small upstream drainage, all of which tend to increase the debris loading.
5. Large organic debris in the coastal redwood environment produces diverse flow conditions, directly causing or influencing the development of pools, riffles, and mid-and side-channel bars. The influence is greatest in small, steep streams, such as the Upper Reach of Little Lost Man Creek, where 60 % of the drop in elevation along the channel profile is associated with large organic debris. A stepped stream profile is produced that provides sediment storage sites covering approximately 40 % of the area of the active channel.
6. Debris is significant in the routing of sediment through the fluvial system by providing an upstream buffer during times of high sediment input from the basin.
7. Many residence times of large organic debris in stream channels of the coastal redwood environment are greater than 100 yrs. Maximum established residence time exceeds 220 yrs and may be much longer.
8. Locations of 800-1000 yr old redwood trees near the banks of the Prairie Creek study reaches suggest that channel configuration and position change little on a time scale of centuries.
9. Management of streams, for maximizing anadromous fish habitat must consider the entire fluvial system and utilize natural stream processes rather than strive for absolute control of the stream by artificial manipulation.

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