AN ABSTRACT OF THE THESIS OF

Richard Friedrich Lammel for the Master of Science
(Name of student) (Degree)

in Forest Engineering presented on July 5th, 1972
(Major) (Date)

Title: Natural debris and logging residue within the stream environment.

Abstract approved: ______________________
(Signature)
Prof. Dr. Henry A. Froehlich

Amounts of natural debris in small headwater streams under old-growth stands of Douglas-fir vary from 6 1/2 tons per 100 ft. of stream to 26 tons per 100 ft. of stream, depending on terrain and timber characteristics and sequence in the natural accumulation-flushing cycle. Approximately 10% of the weight of total debris is in the size-class smaller than 10 cm in diameter.

After falling, there was an increase of debris depending on stream protection measures, falling methods and environmental factors.

After yarding, the amount of total debris was reduced on the average to almost 50% from what it was originally. At the same time, the amount of branch-type debris increased although the amount of finer debris (< 1 cm) decreased.

A wide buffer-strip provided an almost complete physical barrier against debris movements, while a very small buffer-strip provided much less stream protection in terms of logging residue. Cable-assist falling methods minimized breakage and provided for cleaner yarding as compared to conventional timber falling.

Natural Debris and Logging Residue Within the Stream Environment

by

Richard Friedrich Lammel

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of
Master of Science

June 1973

APPROVED:

Associate Professor of Forest Engineering in charge of major

Head of Department of Forest Engineering

Dean of Graduate School

Date thesis is presented July 5, 1972

Typed by Joan Westfall for Richard Lammel

I should like to specially acknowledge the contributions of Professor Dr. Henry A. Froehlich, who outlined the field measurements, spent weeks of hard work with me in the "brush" and critically reviewed this manuscript.

Further, I am indebted to the U. S. Forest Service, Bureau of Land Management and cooperating industries who permitted this study to be taken upon their land, advised in the location of plots and provided data from their files for analyses.

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I. INTRODUCTION

A Problem Analysis

Today's forestry is faced with a variety of problems. There is economic pressure due to rising wages, costs of equipment and insurance and there is pressure provided by the force of public opinion. The more forest industry tries to escape from the economic pressure by means that are determined to increase productivity the more likely it becomes to be accused by the public of deteriorating the environment. In general, the public does not agree that the price for full employment, high standards of living and social security has to be paid with some deterioration of the environment, although this theory is being shared by some contemporary sociologists. (6) Undoubtedly the objections of society should not be neglected, since they represent a valuable and necessary counterweight to industry. However, this all leads to the conclusion that foresters of today have to be concerned about more than trees. They have to produce not only timber but also other options of society such as places that can be used for recreation, streams that can grow fish, etc. At first glance, some of these uses seem to be incompatible. But technology has been improved and we have learned more and more about nature. If foresters try hard and the public is reasonable enough to see their point, then there is a good chance for realistic compromises.

One of the difficult things to combine has always been to harvest timber in watersheds that are used by anadromous fish for spawning. A large number of studies have related to the problem of fish regeneration caused by water quality deterioration. Damage is not only caused by sediments originating from road building, but also through rising temperatures due to the removal of shade-providing trees along the stream. (2, 4, 5, 13, 14)

In addition to this, considerable damage can be caused by logging debris that is placed directly into the stream channel or washed down from the slopes. This organic matter can lower the level of oxygen available to fish to a degree, where survival is seriously affected. (2, 13)

However, before we get deeper into this question, we should consider that catastrophes within eco-systems are not always caused by human beings. Landslides triggered by intense rainfall can increase the load of sediments multifoldly, windstorms can cause rapid changes within the stream eco-system by shade removal and blocking streams by the addition of large quantities of organic matter that reach the stream. This should not be used as an excuse for poor logging practices but rather as a means to a better understanding of stream systems. We should determine what is natural and what isn't and use this knowledge to set up standards.

Where we desire both to harvest trees and to maintain water quality at the level required by the new Oregon Forest Practices Rules, we can break down the issue into these tasks:

1. The logging method must be economically feasible.
2. The impact of the logging operation on water quality must be kept within the limits where the reproduction of fish is guaranteed.

Practically, this means we have to find an economical means of keeping logging debris out of the stream channel. In accomplishing this, there are several routes to go: (1) we can try to minimize the amount of residue in the first place, (2) we can search for measures that keep debris from reaching the channel and (3) we can consider clean-up operations after the logging has been completed.

These possibilities can be combined and modified to whatever suits the specific site best. In the Pacific Northwest the methods of stream protection include:

1. Conventional falling and yarding, clean-up after yarding.
2. Cable-assist falling methods that are designed to minimize breakage, clean-up if necessary.
3. Leaving a streamside buffer-strip, clean-up if necessary.

It is not easy to decide which method is the most effective and which is the cheapest.

Conventional falling and yarding may be money-saving but clean-ups are expensive. Uphill cable-assist falling costs may be much higher but clean-up might not be necessary. Streamside buffer-strips also cost money. If the strips are not logged at all, valuable timber might be wasted, if they are harvested on a selective basis, yarding costs per tree increase tremendously--either way an expensive means. But if the buffer-strip works effectively, provides shade and helps us in avoiding clean-up operations the investment could be worthwhile.

As indicated, we can expect certain benefits combined with certain disadvantages from our choice of logging practices. Unfortunately, this rather speculative approach is not enough for making sound management decisions. It is important to know how effective different methods are in terms of stream protection.

II. OBJECTIVES

Under the title "The Relationship of Timber Harvesting Systems to Logging Residue", the Oregon State University School of Forestry has prepared a Study Plan for the comparison of different timber harvesting techniques. The broad objectives of the study are to determine the effect of different logging methods on the amount and the character of organic debris created by logging operations, especially in stream channels or other sensitive areas and to develop improved systems for handling of logging residue to ameliorate its effect on the environment.

The first phase of the study is to compare the effectiveness of different harvesting techniques in maintaining the stream environment. Data gathering is designed to answer the following questions:

1. What is the extent of natural debris in stream channels?
2. What is the amount of organic matter delivered to stream channels by different logging techniques at various stages of the harvesting process?
3. What is the effect on the stream environment in terms of the extent of channel disturbance and the amount of debris remaining in the channel after completion of logging operations?
4. What are the costs associated with the different stream protection measures?

Out of these questions the first two were selected as the basis for research for this paper.

The different logging techniques in our case are:

1. Cable-assist-falling ("tree-pulling-method"),
2. Leaving a buffer-strip,
3. Conventional falling and yarding.

The goal is to gain more information about the quantity and the quality of organic debris within the stream environment at these stages of the harvesting process:

1. Before falling,
2. After falling,
3. After yarding, before clean-up.

Further research should include a cost/benefit analysis and data is being gathered to accomplish this. However, the complications involved in obtaining complete data made it impossible to publish this part at this moment.

III. LITERATURE REVIEW

There is a variety of publications that are concerned with the impact of logging on fish habitat. (2, 6, 7, 8) These studies mainly deal with sedimentation and temperature changes after logging operations.

Not much is known about the debris situation in stream channels. Quantifications of logging residue have been made under different aspects. DELL and WARD measured fuel volume and weight on clearcuts in the Northwest and found out that about 45% of a total average volume of 7,430 cu.ft./acre could be utilized for manufacture of pulp chips. (7). HOWARD undertook a similar study in 1969/70. His results show volumes per acre ranging from 325 to 3,156 cu.ft., depending on region and ownership situation. (9)

However, in these studies total volumes per clearcut and per acre were measured with no emphasis put on debris accumulations in nearby waterways. Their major concern is the eventual utilization of slash remaining on the site.

FROEHLICH, however, describes flood cycle and debris accumulations in the stream channels of forested watersheds. As he points out, natural accumulations of organic debris in waterways are frequent. They are the result of the natural cycle of tree regeneration - growth - decandence. After blow-downs, wildfire, insect manifestations and other natural calamities, these depositions in stream channels may reach spectacular proportions. Normally, the floatable material of these depositions will be flushed out annually. However, it is not every year that the run-off produced by the annual winter storms is high enough to flush out the whole drainage and large debris may be moved only by floods of large size. Very often then, debris accumulates locally until such time as the stream discharge is high enough to move the material downward. This may be the case only very few times during a 100-year period. (8)

Studies have shown that logging has a very limited impact on the magnitude of run-off produced by a given watershed (1, 16), but logging close to stream channels has a significant impact on the amount of total debris accumulated in the stream channel.

ROTHACHER (15) shows that the debris originating from logging operations tends to be less stable than natural debris. Natural debris, he says, has accumulated over a long period of time and most of it is well stabilized in contrast to logging residue, that practically reaches the stream channel at once. (15)

This is certainly true in cases where no natural catastrophe is involved. However, blow-downs in over-mature stands are likely to have the same impact on the stream environment as logging operations that allow large quantities of logging debris to reach the channel, especially those that are not concerned with clean-up measures.

IV. THE PROJECT

Selection of Research Plots

Out of a number of FS and BLM timber sales, twelve headwater streams were selected for this study, as meeting the criteria of undisturbed areas. These 12 had nearly as possible equal terrain and forest cover. During the summer of 1971, all measurements for the quantification of natural debris before logging have been completed. Due to snow, most of the settings were inaccessible up until May 1972. Because of this, the remeasurements after falling and yarding of only five settings are completed at this moment. Fortunately, the plots, where data collection was possible, are different enough in terms of location as well as of logging methods to establish a satisfying cross-section through most of the varieties we have to deal with.

Four of the settings are located in the Cascades, one (Poodle Creek) is in the Coast Range. All five were felled and yarded within the summer of 1971 and the spring of 1972. None of the plots is within the impact zone of a road. It is assumed that these plots have not been influenced by anything else but natural environmental factors and the actual logging operation.

Information on logging practices, stand- and streamside zone characteristics can be found in Tables I to III.

V. THE PROCEDURE

Sample Plots

In order to establish comparable conditions, we assumed a width of 30 ft. to be the immediate impact zone of the streams. A distance of 400 ft. seemed to be sufficient enough to compensate for local extra-ordinary differences. Therefore, the sample plots were 30 ft. x 400 ft. with the center-line following the middle axis of the stream channel. These plots of 12,000 sq.ft. were divided into 16 sub-areas of 750 sq. ft. each. All plots were marked and numbered with 2 x 2 inch aluminum tags nailed to residual trees or stumps along the creek.

Measurements and Classification of Debris

For all settings, these measurements have been completed:

Quantification of fine, branch-type and coarse organic debris

- before falling
- after falling
- after yarding.

The classification of fine, branch-type and coarse debris was made for mainly two reasons. Fine debris less than a centimeter in diameter shows a higher BOD per unit weight in comparison to larger fractions. Branch-type material (1-10 cm), and coarse debris (>10 cm) were placed in different categories due to differences in the way they can be handled in clean-up operations and again for eventual differences in BOD per unit weight. These major classes, for the reason of providing more meaningful results, again were classified as follows:

1.	Fine debris	a) < 1 cm
		b) 1 - 3 cm
2.	Branch-type debris	a) 3 - 10 cm
3.	Coarse debris	pieces of more than 10 cm diameter and 30 cm length and of a volume of
		a) < 1 cu.ft.
		b) 1-4.99 cu.ft.
		c) 5-9.99 cu.ft.
		d) 10 and > 10 cu.ft.

Measurement of branch-type and fine debris:

All size classes in question were measured and computed after the Line Intersect Method described by VAN WAGNER (17) as modified by BROWN (3). This method has been proved to work satisfactorily for estimating the volume and weight of slash or other fuel on the ground. For our purpose, we determined the mean average diameters of fine and branch-type debris after several hundred measurements. Mean average diameters were:

0.423 cm for fine debris < 1 cm

1.792 cm for fine debris 1- 3 cm

5.049 cm for branch-type debris 3-10 cm

These diameters were entered into a modification of VAN WAGNER's formula

$$V = \frac{\pi^2 \sum d^2}{8L} . \quad (15)$$

where

$\sum d^2$ = count of intersections of all particles in diameter class x mean average diameter

V = volume of wood per unit area

d = mean average diameter of size-class

and

L = length of sample line.

For obtaining an objective sample line of constant length a metal frame providing a sample line length of 30 cm was used. The total number of sample measurements was 68 per plot, randomly distributed over 17 cross-sections perpendicular to the stream axis established at the ends of each sub-area. For calculation and computation, a MONROE 1665 programmable calculator was used.

Measurement of coarse debris:

The coarse debris was measured piece by piece with the help of calipers and a steel tape in terms of diameter of the big end, diameter at the small end and length. Pieces that were assumed to break up completely due to lack of solid wood fiber if they were moved down-stream were not taken under consideration. The programmable calculator MONROE 1665 was used for the computation of data. This was a relatively easy way to obtain volume per piece (SMALIAN FORMULA), volume per sub-area, volume per plot and average volume per unit length of stream.

Conversion of measurement units:

In order to provide better and more meaningful answers, the results, originally obtained in English volume units per total length of plot in feet, were converted into both English and Metric Weight units per 100 feet of stream, respectively, 100 m of stream. This normally rather time-consuming conversion was made with a simple program for the MONROE calculator (card-reader-type).

We assumed the specific weight of this organic debris to be 0.58 at an average moisture content of 10% (12).

As mentioned before, the coarse debris was segregated into three classes, referring to the fact that pieces of different volume and weight make the use of different equipment necessary while cleaning up.

VI. RESULTS

TABLE I. DESCRIPTION OF LOGGING PRACTICES

East Buck 1	USFS-sale, high-lead, clearcut 2 sides of the stream, tree-pulling-method was applied (cable-assist-falling).
East Buck 12	USFS-sale, high-lead, clearcut 2 sides of the stream, tree-pulling-method was applied (cable-assist-falling).
Poodle Creek	BLM-sale, high-lead and cat, clearcut 1 side of the stream, partial cut other side, hardwood buffer-strip, buffer-strip is not continuous due to cold-decks that have been swung across the creek, average width of buffer: 15 ft.
Happy Ridge	BLM-sale, high-lead, clearcut 1 side of the creek, mixed species buffer-strip, buffer-strip is wide (150 ft.) and effective.
Patchquilt 6	USFS-sale, high-lead, conventional high-lead setting, no special falling techniques, no buffer-strip, clearcut 1 side of the creek.

TABLE II. DESCRIPTION OF STAND CHARACTERISTICS

SETTING	AVE. DBH inches	AVE. VOL. PER TREE MBF	VOL./ACRE (16' log) MBF	ESTIMATED STAND DEFECT, %
East Buck 1	39	1.31	55.9	30
East Buck 12	39	1.31	55.9	30
Happy Ridge	36	2.10	43.0	36
Poodle Creek	32	2.53	45.0*	36
Patchquilt 6	38	1.46	49.9	31

* This value was estimated since no exact figure was available.

TABLE III. DESCRIPTION OF STREAMSIDE ZONES

East Buck 1	stream gradient	22°
	side slopes	36°, broken by benches
	ave. streamside zone width	20 ft.
	streamside vegetation	hemlock, redcedar, yew
East Buck 12	stream gradient	20°
	side slopes	43°, several 100 ft. long and continuous
	ave. streamside zone width	5 ft.
	streamside vegetation	hemlock, redcedar, yew
	- 45 ft. waterfall above sample plot -	
Poodle Creek	stream gradient	5°
	side slopes	23° partial cut side 37° clearcut side
	ave. streamside zone width	17 ft.
	streamside vegetation	maple, alder, dense cover of devil's club
Happy Ridge	stream gradient	11°
	side slopes	35°, broken by benches
	ave. streamside zone width	18 ft.
	streamside vegetation	hemlock, redcedar, Douglas-fir
Patchquilt	stream gradient	7°
	side slopes	33°, broken by benches
	ave. streamside zone width	19 ft.
	streamside vegetation	redcedar, hemlock

TABLE IV. TOTAL VOLUME OF ORGANIC DEBRIS
(cu. ft./100 ft. of stream)

Setting	Before Falling	After Falling	After Yarding
East Buck 1	642.650	1533.066	369.802
East Buck 12	1401.975	1966.825	623.231
Poodle Creek	407.626	520.821	234.371
Happy Ridge	806.664	807.066	807.066
Patchquilt	343.337	1273.090	286.900

TOTAL VOLUME OF ORGANIC DEBRIS
(m^3/100 m of stream)

Setting	Before Falling	After Falling	After Yarding
East Buck 1	59.696	142.409	34.351
East Buck 12	130.230	182.699	57.950
Poodle Creek	37.865	48.316	21.770
Happy Ridge	74.932	74.970	74.970
Patchquilt	31.892	118.258	27.300

TABLE V. TOTAL WEIGHT OF ORGANIC DEBRIS
(tons/100 ft. of stream)

Setting	Before Falling	After Falling	After Yarding
East Buck 1	11.935	28.267	7.711
East Buck 12	25.877	36.449	11.921
Poodle Creek	7.573	9.717	4.546
Happy Ridge	14.916	14.923	14.923
Patchquilt	6.461	23.618	5.540

TOTAL WEIGHT OF ORGANIC DEBRIS
(tons/100 m of stream)

Setting	Before Falling	After Falling	After Yarding
East Buck 1	35.528	84.133	21.165
East Buck 12	77.019	108.487	35.478
Poodle Creek	22.541	28.920	13.529
Happy Ridge	44.397	44.419	44.419
Patchquilt	19.228	70.297	16.506

TABLE VI. VOLUME OF COARSE DEBRIS
(> 10 cm diameter and 30 cm length)
in cu.ft./100 ft. of stream

Setting	Before Falling	After Falling	After Yarding
East Buck 1	611.655	1490.616	314.742
East Buck 12	1359.002	1884.040	540.191
Poodle Creek	387.568	485.201	193.550
Happy Ridge	777.717	778.119	778.119
Patchquilt	313.844	1215.624	239.690

VOLUME OF COARSE DEBRIS
(> 10 cm diameter and 30 cm length)
in m^3/100 m of stream

Setting	Before Falling	After Falling	After Yarding
East Buck 1	56.818	138.466	29.237
East Buck 12	126.239	175.010	50.179
Poodle Creek	36.002	45.071	17.979
Happy Ridge	72.243	72.281	72.281
Patchquilt	29.153	112.921	22.265

TABLE VII. WEIGHT OF COARSE DEBRIS
(>10 cm diameter and 30 cm length)
in tons/100 ft. of stream

Setting	Before Falling	After Falling	After Yarding
East Buck 1	11.167	27.215	5.746
East Buck 12	24.812	34.398	9.863
Poodle Creek	7.076	8.859	3.534
Happy Ridge	14.199	14.206	14.206
Patchquilt	5.730	22.194	4.370

WEIGHT OF COARSE DEBRIS
(> 10 cm diameter and 30 cm length)
in To/100 m of stream

Setting	Before Falling	After Falling	After Yarding
East Buck 1	33.238	81.002	17.104
East Buck 12	73.850	102.380	29.354
Poodle Creek	21.063	26.367	10.518
Happy Ridge	42.262	42.284	42.284
Patchquilt	17.054	66.059	13.025

TABLE VIII. VOLUME OF BRANCH-TYPE DEBRIS
(3 - 10 cm)
in cu.ft./100 ft. of stream

Setting	Before Falling	After Falling	After Yarding
East Buck 1	22.263	28.335	46.551
East Buck 12	34.406	67.802	69.826
Poodle Creek	15.180	26.311	31.371
Happy Ridge	23.275	23.275	23.275
Patchquilt	21.251	37.443	32.383

VOLUME OF BRANCH-TYPE DEBRIS
(3 - 10 cm)
in m^3/100 m of stream

Setting	Before Falling	After Falling	After Yarding
East Buck 1	2.068	2.630	4.324
East Buck 12	3.196	6.297	6.485
Poodle Creek	1.410	2.444	2.914
Happy Ridge	2.162	2.162	2.162
Patchquilt	1.974	3.478	3.007

TABLE IX. WEIGHT OF BRANCH-TYPE DEBRIS
(3 - 10 cm)
in tons/100 ft. of stream

Setting	Before Falling	After Falling	After Yarding
East Buck 1	0.552	0.702	1.754
East Buck 12	0.853	1.680	1.730
Poodle Creek	0.376	0.652	0.777
Happy Ridge	0.577	0.577	0.577
Patchquilt	0.527	0.928	0.802

WEIGHT OF BRANCH-TYPE DEBRIS
(3 - 10 cm)
In To/100 m of stream

Setting	Before Falling	After Falling	After Yarding
East Buck 1	1.642	2.090	3.433
East Buck 12	2.538	5.001	5.150
Poodle Creek	1.119	1.940	2.314
Happy Ridge	1.716	1.716	1.716
Patchquilt	1.567	2.761	2.388

TABLE X. VOLUME OF FINE DEBRIS
(cu.ft./100 ft. of stream)

	Before Falling	After Falling	After Yarding
A) 0 - 1 cm			
East Buck 1	2.738	7.744	2.020
East Buck 12	3.214	5.554	5.696
Poodle Creek	1.820	2.045	3.079
Happy Ridge	1.976	1.976	1.976
Patchquilt	1.998	8.555	6.030
B) 1 - 3 cm			
East Buck 1	5.989	6.371	6.498
East Buck 12	5.352	9.429	7.518
Poodle Creek	3.058	7.263	6.311
Happy Ridge	3.695	3.695	3.695
Patchquilt	6.244	11.468	8.792
TOTAL			
East Buck 1	8.727	14.116	8.518
East Buck 12	8.566	14.983	13.214
Poodle Creek	4.878	9.308	9.450
Happy Ridge	5.671	5.671	5.671
Patchquilt	8.242	20.023	14.822

TABLE XI. VOLUME OF FINE DEBRIS
(m^3/100 m of stream)

	Before Falling	After Falling	After Yarding
A) 0 - 1 cm			
East Buck 1	0.254	0.719	0.188
East Buck 12	0.299	0.516	0.529
Poodle Creek	0.169	0.190	0.286
Happy Ridge	0.180	0.184	0.184
Patchquilt	0.186	0.796	0.560
B) 1 - 3 cm			
East Buck 1	0.556	0.592	0.604
East Buck 12	0.497	0.876	0.698
Poodle Creek	0.284	0.675	0.592
Happy Ridge	0.343	0.343	0.343
Patchquilt	0.580	1.065	0.817
TOTAL			
East Buck 1	0.810	1.311	0.792
East Buck 12	0.796	1.392	1.227
Poodle Creek	0.453	0.865	0.878
Happy Ridge	0.527	0.527	0.527
Patchquilt	0.766	1.860	1.377

TABLE XII. WEIGHT OF FINE DEBRIS
(tons/100 ft. of stream)

	Before Falling	After Falling	After Yarding
A) 0 - 1 cm			
East Buck 1	0.068	0.192	0.050
East Buck 12	0.079	0.138	0.141
Poodle Creek	0.045	0.050	0.076
Happy Ridge	0.049	0.049	0.049
Patchquilt	0.049	0.212	0.149
B) 1 - 3 cm			
East Buck 1	0.148	0.158	0.161
East Buck 12	0.133	0.234	0.186
Poodle Creek	0.076	0.180	0.158
Happy Ridge	0.092	0.092	0.092
Patchquilt	0.155	0.284	0.218
T O T A L			
East Buck 1	0.216	0.350	0.211
East Buck 12	0.212	0.372	0.327
Poodle Creek	0.121	0.230	0.234
Happy Ridge	0.141	0.141	0.141
Patchquilt	0.204	0.496	0.367

TABLE XIII. WEIGHT OF FINE DEBRIS
(To/100 m of stream)

	Before Falling	After Falling	After Yarding
A) 0 - 1 cm			
East Buck 1	0.202	0.571	0.149
East Buck 12	0.237	0.410	0.420
Poodle Creek	0.134	0.151	0.227
Happy Ridge	0.146	0.146	0.146
Patchquilt	0.147	0.631	0.445
B) 1 - 3 cm			
East Buck 1	0.442	0.470	0.480
East Buck 12	0.395	0.695	0.554
Poodle Creek	0.226	0.536	0.469
Happy Ridge	0.273	0.273	0.273
Patchquilt	0.460	0.846	0.648
TOTAL			
East Buck 1	0.644	1.041	0.629
East Buck 12	0.632	1.105	0.974
Poodle Creek	0.360	0.687	0.696
Happy Ridge	0.419	0.419	0.419
Patchquilt	0.607	1.477	1.093

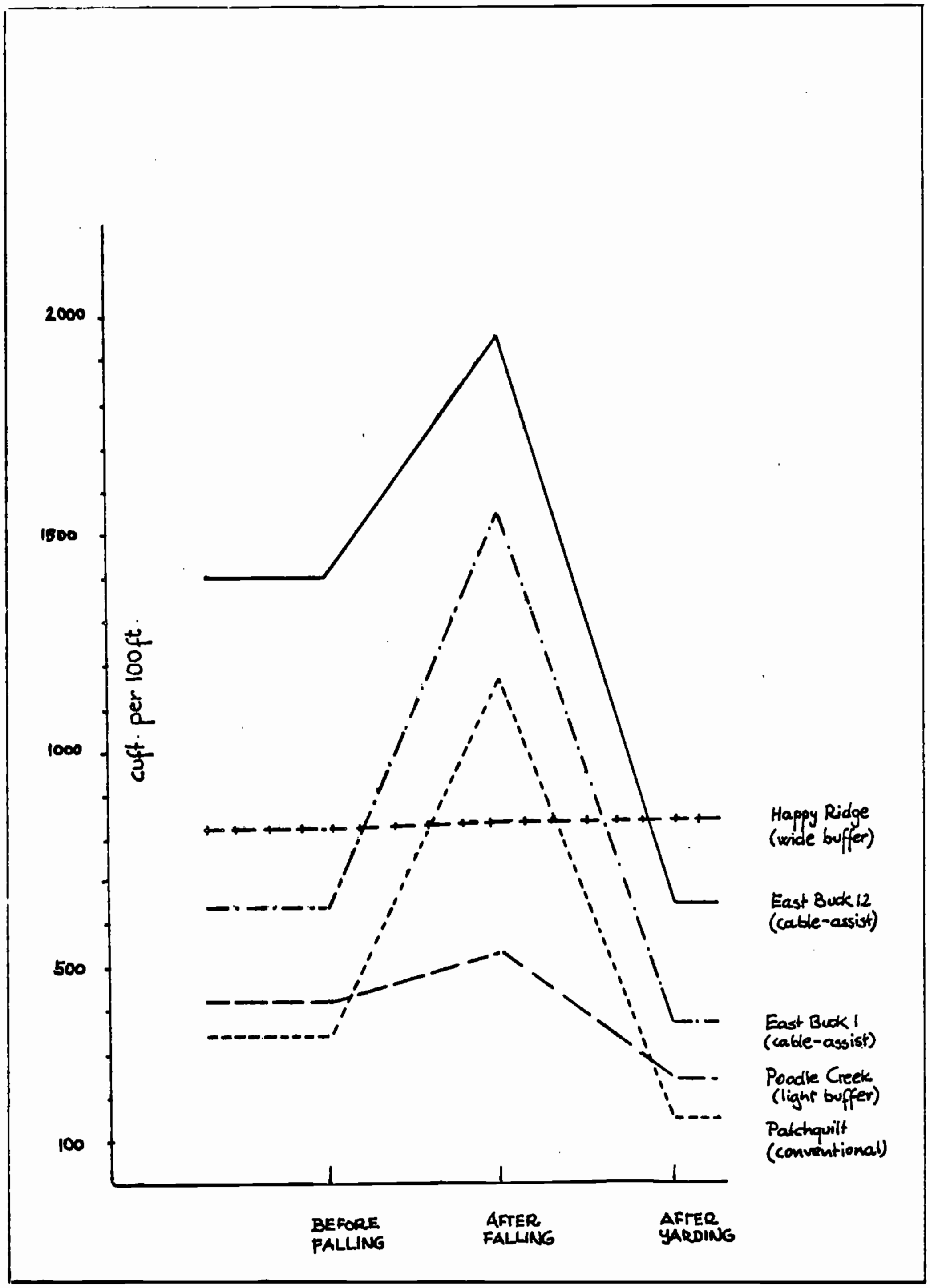

Figure 1. Change of total organic debris.

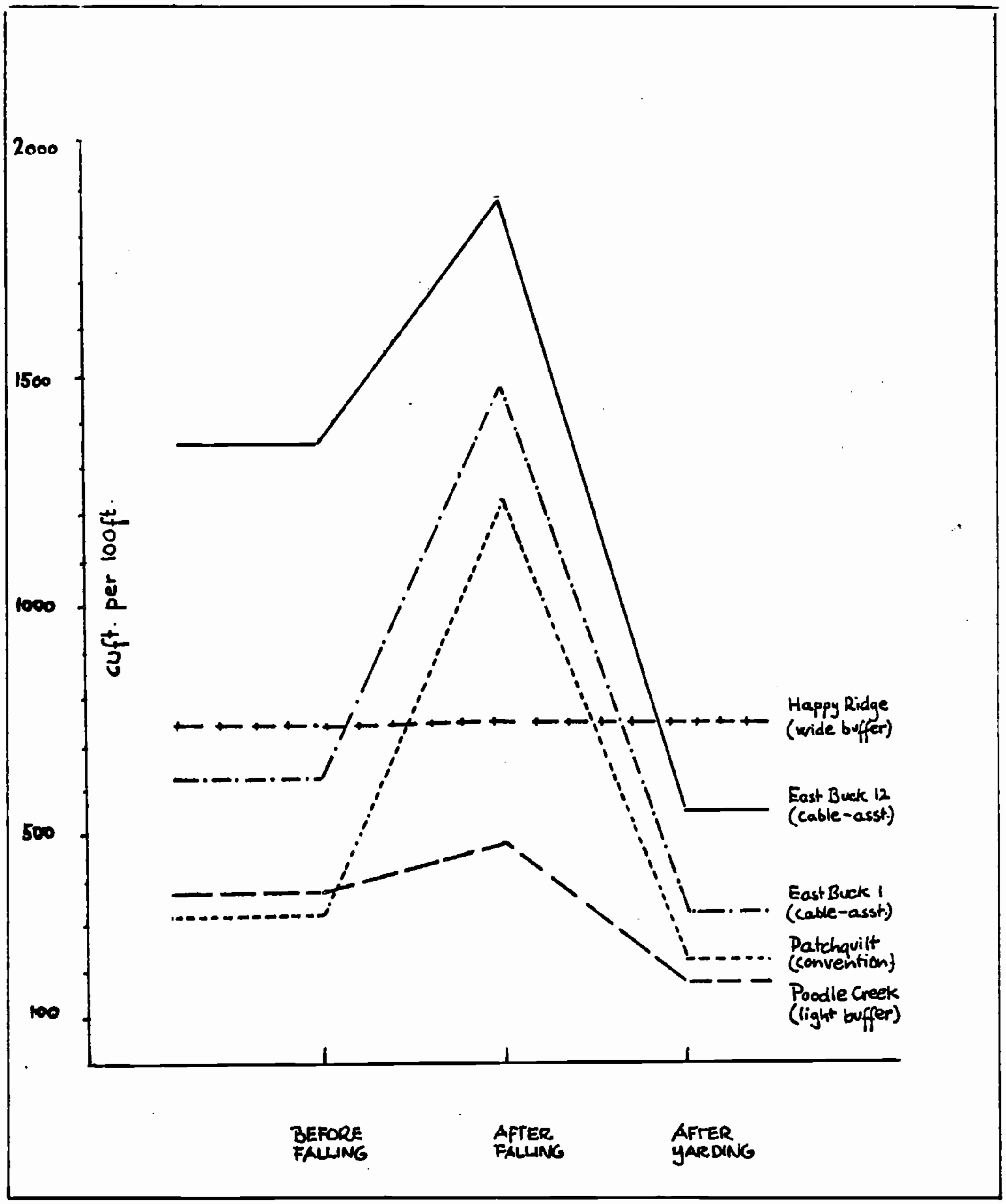

Figure 2. Change of coarse debris (> 10 cm).

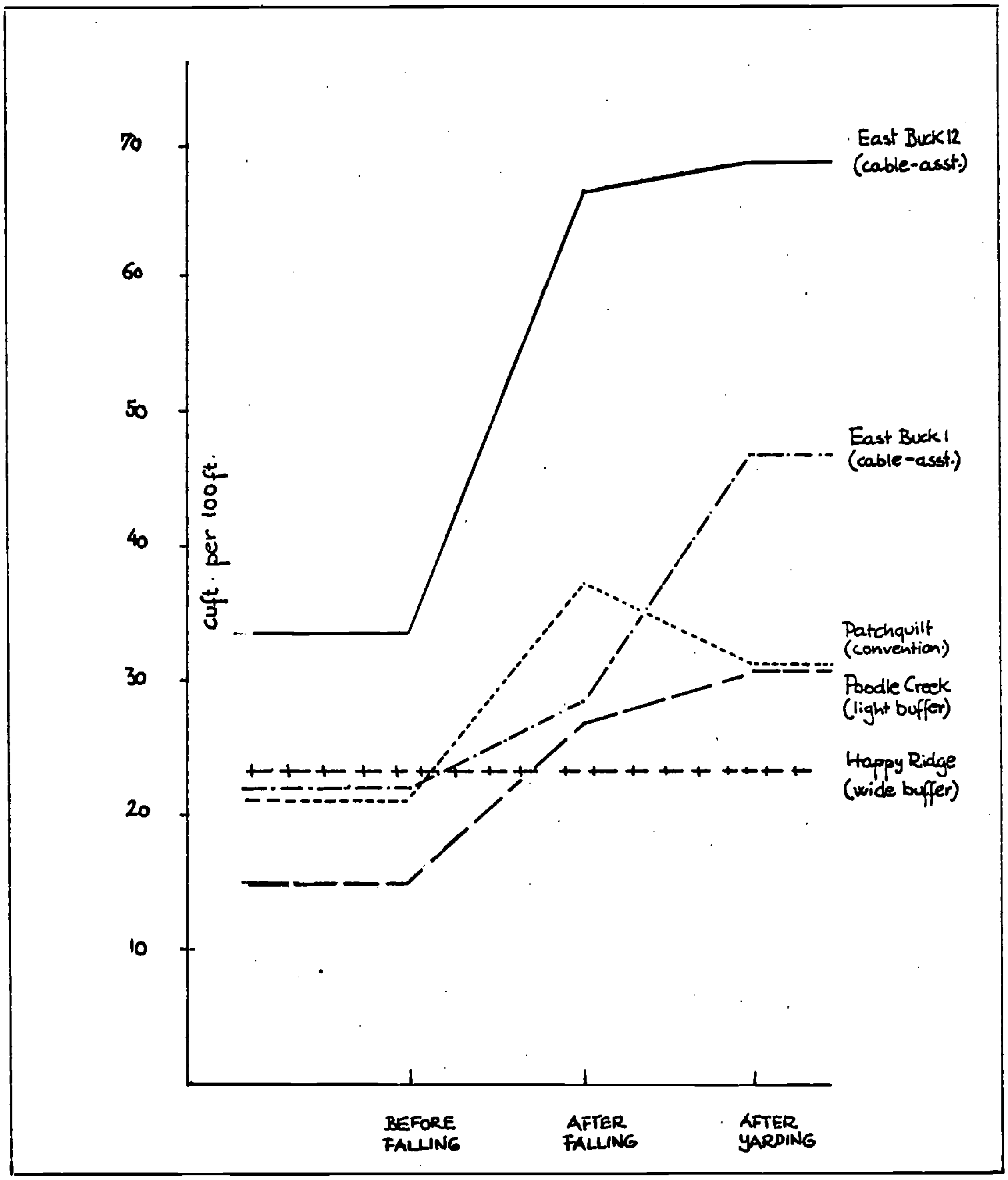

Figure 3. Change of branch-type debris (3-10 cm).

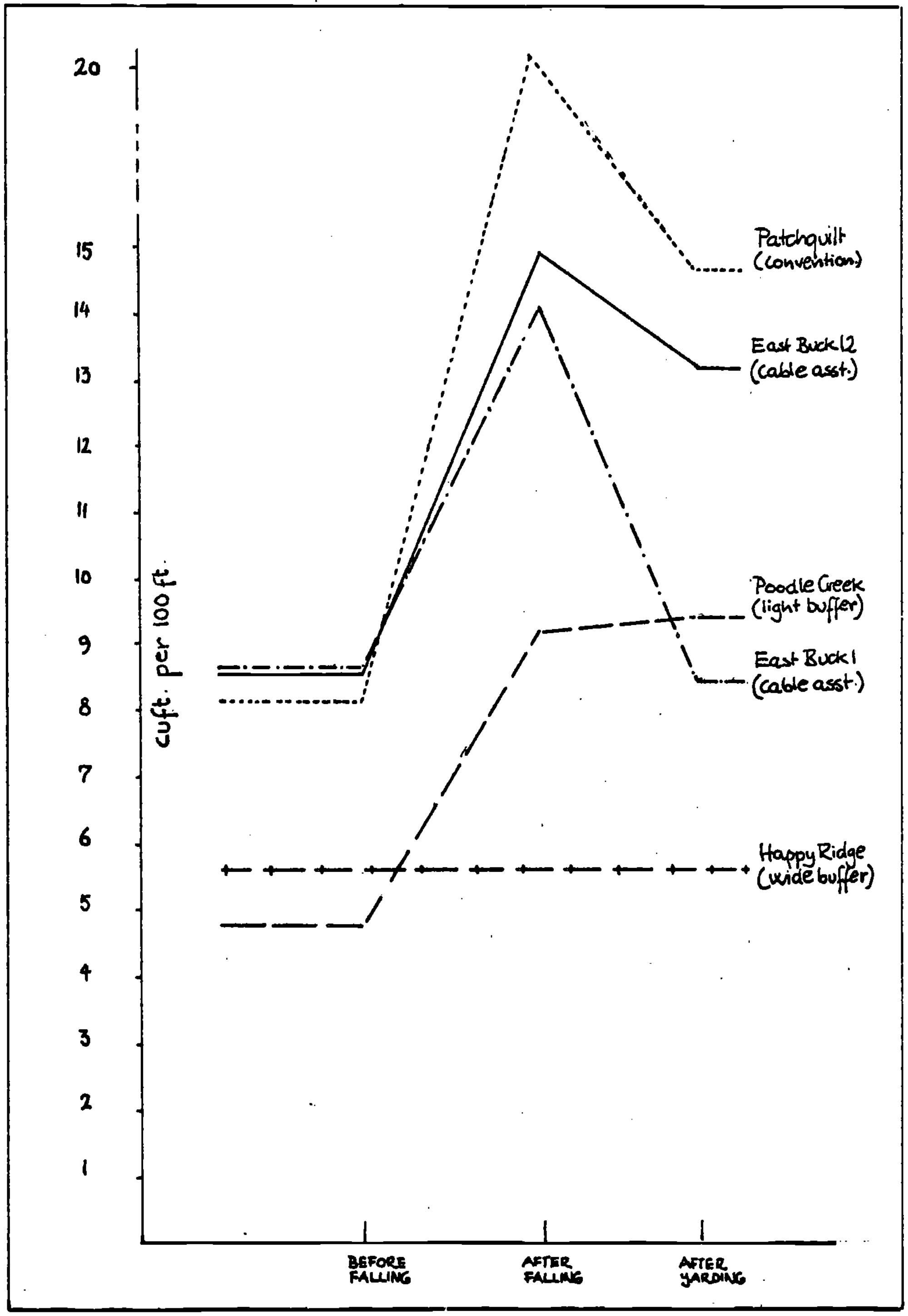

Figure 4. Change of total fine debris (< 3 cm).

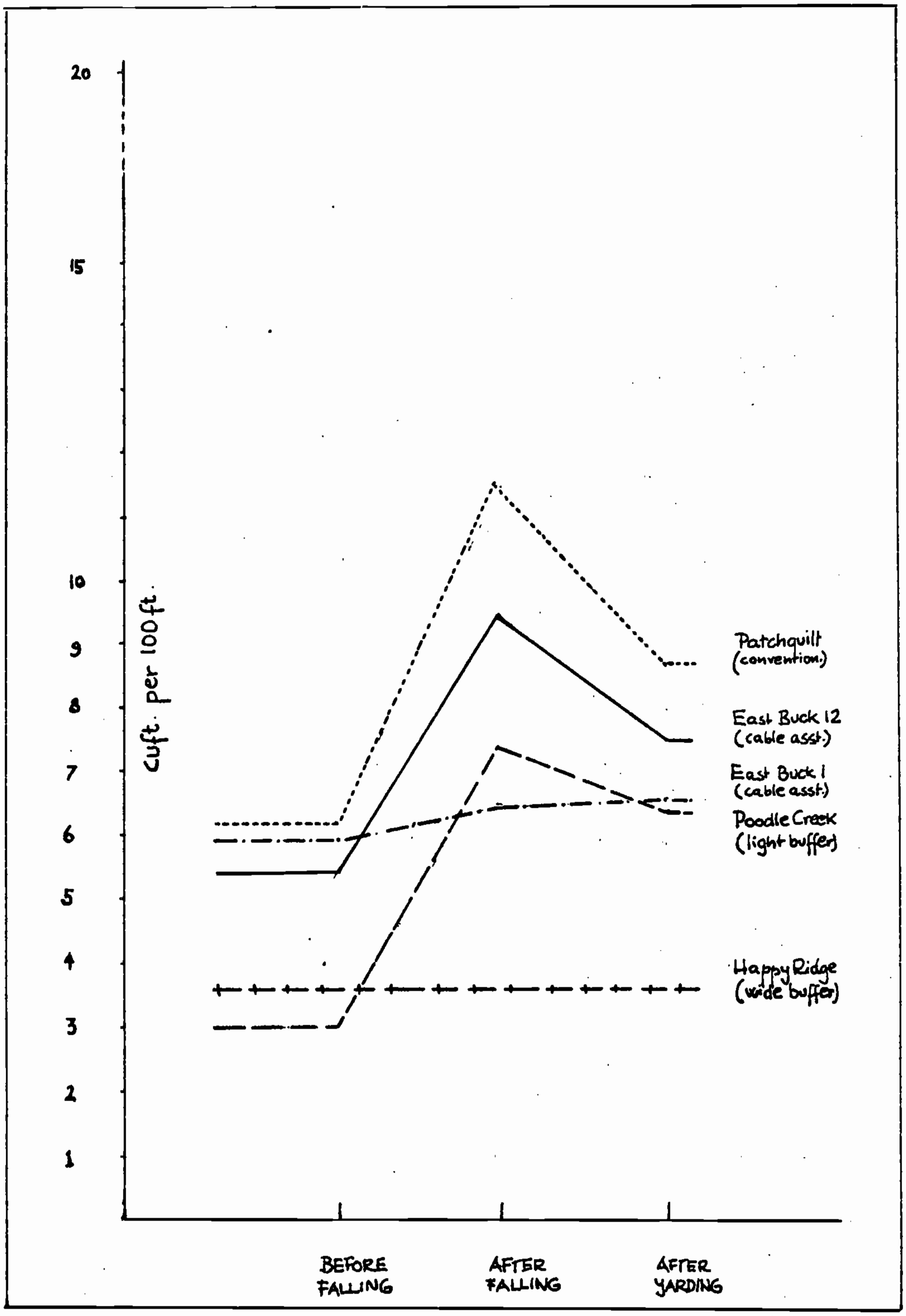

Figure 5. Change of fine debris (1-3 cm).

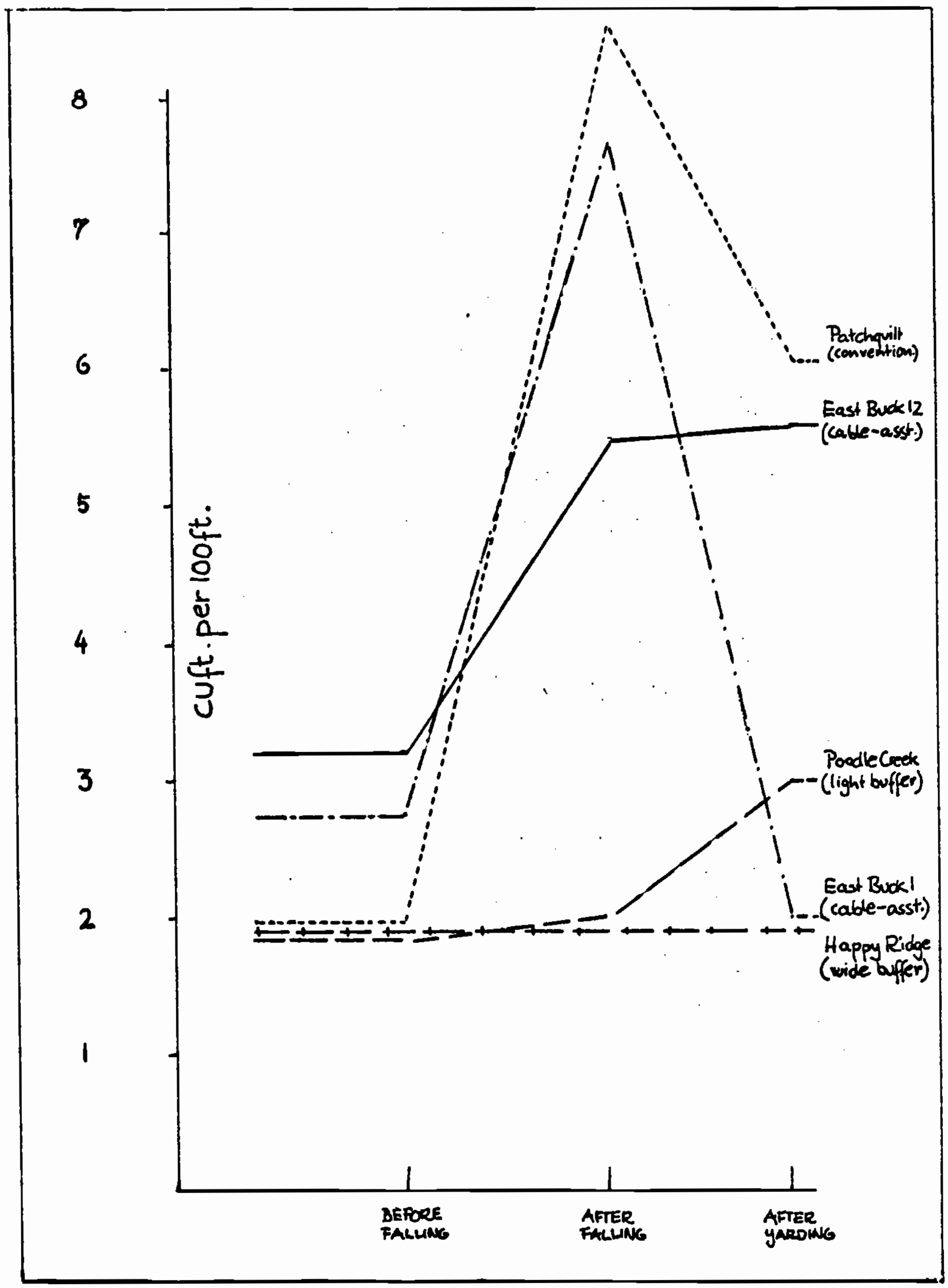

Figure 6. Change of fine debris (< 1 cm).

TABLE XIV. NUMBER OF PIECES AND WEIGHT OF PIECES OF COARSE DEBRIS PER 100 FT. OF STREAM (4 SIZE-CLASSES)

Setting		1 cu.ft.		1 - 4.99 cu.ft.		5 - 9.99 cu.ft.		10.00 and 10 cu.ft.	
		pieces	cu.ft.	pieces	cu.ft.	pieces	cu.ft.	pieces	cu.ft.
East Buck 1 (cable-assist)	before f.	6.5	3.68	6.3	14.55	1.8	10.83	9.9	582.59
	after f.	7.1	3.56	7.8	18.22	5.3	34.32	24.3	1433.78
	after y.	9.3	4.86	12.3	30.96	3.3	24.12	8.3	255.27
East Buck 12 (cable-assist)	before f.	2.0	1.05	5.8	12.35	4.3	27.93	22.3	1317.68
	after f.	6.8	3.79	7.9	18.97	6.3	41.17	33.1	1820.11
	after y.	9.8	5.41	7.9	19.81	5.5	37.83	5.4	477.77
Poodle Creek (light buffer)	before f.	5.8	3.10	4.3	8.98	1.3	9.51	3.8	365.93
	after f.	2.7	2.26	2.7	6.77	0.9	5.74	5.1	470.49
	after y.	11.3	4.35	4.8	11.08	0.5	3.54	2.1	174.58
Happy Ridge (wide buffer)	before f.	12.0	6.85	11.5	25.33	6.5	42.33	13.3	703.21
	after f.								
	after y.	NO SIGNIFICANT CHANGE							
Patchquilt (conventional)	before f.	11.3	5.85	7.8	17.03	3.5	22.99	6.0	267.98
	after f.	10.3	5.76	12.3	31.17	5.3	36.55	17.4	1142.14
	after y.	6.0	3.11	7.5	18.41	4.8	31.46	7.0	186.71

TABLE XV. CHANGE OF VOLUME OF ORGANIC DEBRIS IN PERCENT (4 SIZE-CLASSES)

Setting	Size-Class	Before Falling	After Falling	After Yarding
East Buck 1 (cable-assist)	1 cm	100	282.8	73.8
	1-3 cm	100	106.4	108.5
	3-10 cm	100	127.3	209.1
	10 cm	100	243.7	51.1
East Buck 12 (cable-assist)	1 cm	100	172.8	177.2
	1-3 cm	100	176.2	140.5
	3-10 cm	100	197.1	202.9
	10 cm	100	138.6	39.7
Poodle Creek (light buffer)	1 cm	100	112.4	168.9
	1-3 cm	100	237.5	208.3
	3-10 cm	100	173.3	206.7
	10 cm	100	125.2	49.9
Happy Ridge (wide buffer)	1 cm	100	100.0	100.0
	1-3 cm	100	100.0	100.0
	3-10 cm	100	100.0	100.0
	10 cm	100	100.0	100.0
Patchquilt (conventional)	1 cm	100	429.9	301.8
	1-3 cm	100	183.7	140.8
	3-10 cm	100	176.2	152.0
	10 cm	100	387.3	76.3

TABLE XVI. CHANGE OF TOTAL VOLUME OF ORGANIC DEBRIS IN PERCENT

Setting	Before Falling	After Falling	After Yarding
East Buck 1 (cable-assist)	100	238.5	57.5
East Buck 12 (cable-assist)	100	140.3	44.5
Poodle Creek (light buffer)	100	127.8	57.4
Happy Ridge (wide buffer)	100	100.0	100.0
Patchquilt (conventional)	100	370.8	85.6

VII. DISCUSSION OF RESULTS

One of the things that became evident is the variability of different stream environments. Our study areas include streams of the same order, similar discharge and similar characteristics of the surrounding stands (Tables I-III). Nevertheless, the amounts of total natural debris vary from 6 1/2 tons per 100 ft. of stream (Patchquilt) up to 26 tons per 100 ft. (East Buck 12) (Table IV).

Undoubtedly, one reason for this is differences in the shape of these channels. Natural debris coming downslope did not concentrate in Patchquilt but would be rather held back by benches and rocks above the streamside zone, whereas the long, steep, unbroken slopes of East Buck 12, that are much steeper than those of Patchquilt, did not keep debris originating from further above from sliding into the channel. Another reason that could account for the differences is that not all streams are flushed out by the same storm. Different watersheds have different precipitation characteristics, have different response factors, etc. This means that some of the streams could have been flushed out not too long ago and are relatively "empty" at the present time, whereas others only accumulated barriers of debris locally and are likely to be sluiced out after a heavy storm or a storm of long duration in the future.

On the average, about 1/10 of the weight and volume of total debris is made up by debris smaller than 10 cm diameter. However, the amounts of this smaller debris show much less variation than the coarse debris. The range is from .5 tons/100 ft. up to 1 ton/100 ft.

The much smaller variation of this material suggests that factors such as the shape of the stream channel are less important for the movement of smaller pieces than they are for coarse material. Smaller pieces are more mobile and tend to reach the lowest point of the channel cross-section far less dependent on the slope of the terrain than larger pieces. After timber falling, all streams were found to be more or less influenced by the operation. The least affected stream was the one of Happy Ridge. Only one piece of 0.2 cu.ft. was found to be new after falling, a change of less than 1 percent. Finer debris remained unchanged. This can be explained by the fact that the Happy Ridge sale was designed to leave a wide buffer-strip between the operation area and the stream channel. This buffer-strip, consisting of Douglas-fir, hemlock, redcedar, and intermingled hardwoods, is 80-150 ft. wide and proved to be absolutely effective to keep additional debris out of the reach of the creek. Questions about how much less buffer would have served the same purpose and how much timber could have been used out of this strip without lowering its efficacy are justified but go beyond the objectives of this paper. All the other study streams show increases in both coarse and fine debris depending on the lay-out of the operation and on natural conditions of the stream environment.

The size-class that increased most spectacularly in terms of total volume was the size-class of pieces larger than 10 cm diameter and more than 30 cm length. (Table VI)

Patchquilt, the setting where only conventional methods were employed, showed a 287% increase for coarse debris, whereas Poodle Creek, having a small buffer-strip, came closest to the "no change" of Happy Ridge with an increase of only 25%. East Buck 1 was harvested by the "tree-pulling-method", where all trees are felled with the assistance of a winch. It had a 38% increase for this size-class. East Buck 12, where the same method has been applied, had a rather unexpected increase of 144%. This might be due more to the characteristics of this setting than to the fact that tree-pulling was not an effective means of minimizing the amount of logging residue reaching the stream environment. As indicated before, East Buck 12 includes a stream channel with extremely steep and long unbroken slopes. Even pieces that are not within the immediate stream impact zone are likely to slide into the stream channel, if they are not completely removed.

Tree-pulling seemed to minimize breakage to a large extent, which means that most of the large pieces can be completely yarded and utilized. If East Buck 12 would have been treated in a conventional way, the breakage would have been enormous and the amount of remaining broken tops would have far exceeded the result of the conventional setting Patchquilt.

The change of debris smaller than 1 cm follows the same pattern of the coarse debris (Table XI). Both buffer strips were more effective than the tree-pulling method. However, by far the largest increase for both coarse debris and that smaller than 1 cm debris became evident for the conventional setting.

Surprisingly different from this pattern is the change of 1 - 3 cm debris (Table XI). The conventional setting was found to have even less debris of this size-class than Poodle Creek, which was designed with a narrow buffer-strip. This might indicate that there was more potential debris of this size-class existent in this setting. This can be explained by the fact that in this setting there was a typical Coast-Range-type vegetation along the stream, consisting of maple and alder. Accumulations of twigs and little branches that did not fall into the smaller size-class resulting from the stream-side hardwood vegetation (no needles) account for this phenomenon. At the same time, the narrow buffer-strip did not prove to be a physical barrier against this type of residue.

This is also supported by the pattern of change for branch-type debris after falling (Table VIII). Poodle Creek shows a high increase together with East Buck 12 and Patchquilt for this size-class, but did not show the same high increase for finer debris. East Buck 12 and Patchquilt increased considerably for both size-classes, what again leads to the conclus ion that the difference in the vegetative cover along the channel might be the key factor.

Putting together these results, it shows that there exists a problem in comparing different settings resulting from natural differences amongst stream channels. However, it can be said that the biggest change occurred for the setting where no stream protection measure was applied. Tree-pulling reduces breakage and helps to minimize the amount of broken tops, etc., in the channel. Undoubtedly, the most effective means as far as debris is concerned is to leave a buffer strip. Down to what width of buffer full protection is guaranteed cannot be defined by this study, but buffer-strips that are of the width and quality of the one along Poodle Creek cannot establish a physical barrier against debris movements.

After yarding, the amount of coarse debris was reduced markedly (Table VI). It is somewhat surprising that even before any cleanup requirements had been met, 23% to 50% of the natural coarse debris has been removed. This supports the idea that much of the wind-blown trees that are present in the stream channels can be partially utilized or at least be removed.

Debris of the size-classes smaller than 10 cm either increased after yarding or was somewhat less from what it was after falling (Tables VIII-XIII). Some of it might have been yarded out of the channel along with larger pieces such as broken tops, some of it might have been freshly added by breakage or ground disturbance during the yarding process, some of it might have been flushed out already, specially the more mobile pieces of smaller diameters.

The change of total organic debris after yarding (Table IV) fits closely the pattern of change of coarse debris, since changes of the amount of finer debris do not become relevant in terms of percent of total debris volume.

In order to provide a better picture for what happened to pieces of the largest size-class (bigger than 10 cm), a table was prepared that shows the change of the number of pieces per 100 ft. of stream together with the volume represented by these. (Table XIV)

The general trend shows that in most cases the number of small pieces increases during the harvesting operation, whereas the number of pieces of the volume between 1 and 10 cu.ft. remains in the same magnitude. The number of larger pieces increased significantly after falling but was markedly reduced after yarding. However, the change after falling and yarding is even more evident in terms of volume (in contrast to the change in number of pieces), which leads to the conclusion that some of the large pieces became broken into parts during the operation. Generally, the average diameters per piece of a bigger volume than 10 cu.ft. became reduced after yarding.

VIII. CONCLUSION

The results show that even before any human activity took place, the stream channels are loaded with natural debris up to 26 tons per 100 ft. of stream, depending on stand characteristics of the old-growth Douglas-fir and the natural flushing-cycle. Logging activities tend to increase the amount of debris in the channels during timber falling, whereas the amount of debris will be reduced to even less than the original value after yarding.

The amount of pieces that are smaller than 10 cm in diameter will generally increase after falling, but pieces of the smallest size-class such as small twigs and needles will be reduced in number and volume after yarding. Possibly, these pieces are mobile enough to be washed down stream after a short period of time.

Stream protection measures such as buffer-strips or cable-assist falling can provide adequate protection.

Buffer-strips have to be continuous and wider than 15 ft. but can be probably narrower than 150 ft. to establish an effective physical barrier.

Because of the high costs or physical impracticality of buffer-strips the alternative solution "cable-assist-falling" might be considered. This method minimizes breakage and provides for cleaner yarding. The traditional way of falling and yarding seems to be not the way to go in the future. As costs of the clean-up and handling the debris in some manner are developed it may be shown that the additional costs of the stream protection measures will be offset by savings in clean-up costs.

APPENDIX

Photographs provided

by

Professor Dr. H. A. Froehlich

Figure 7. Happy Ridge. Windblown trees and finer debris accumulating at barrier without any influence through logging.

Figure 8. Patchquilt. An example of debris accumulations under undisturbed conditions before logging.

Figure 9. Patchquilt. More than twice as much debris is added during falling.

Figure 10. Poodle Creek. A small buffer-strip of hardwoods still permitted a 28% increase of organic material to enter the streamside zone during falling.

Figure 11. Patchquilt. A great deal of the original coarse debris has been removed during yarding.

Figure 12. Patchquilt. Fine debris and branch-type debris remained in the streamside zone after yarding.

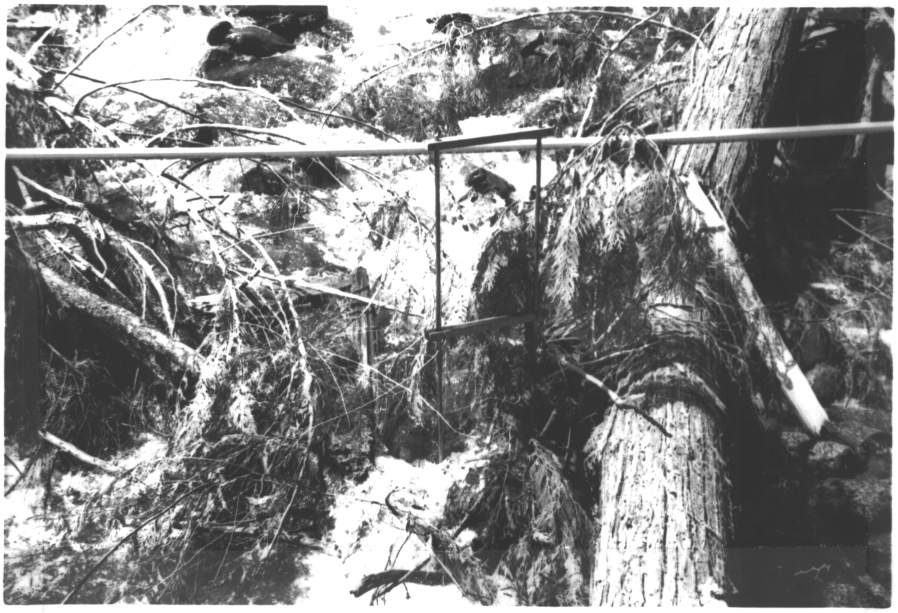

Figure 13. Measuring rod and sampling frame were used to quantify fine and branch-type debris.

Figure 14. Coarse debris was measured with calipers and steel tape.

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