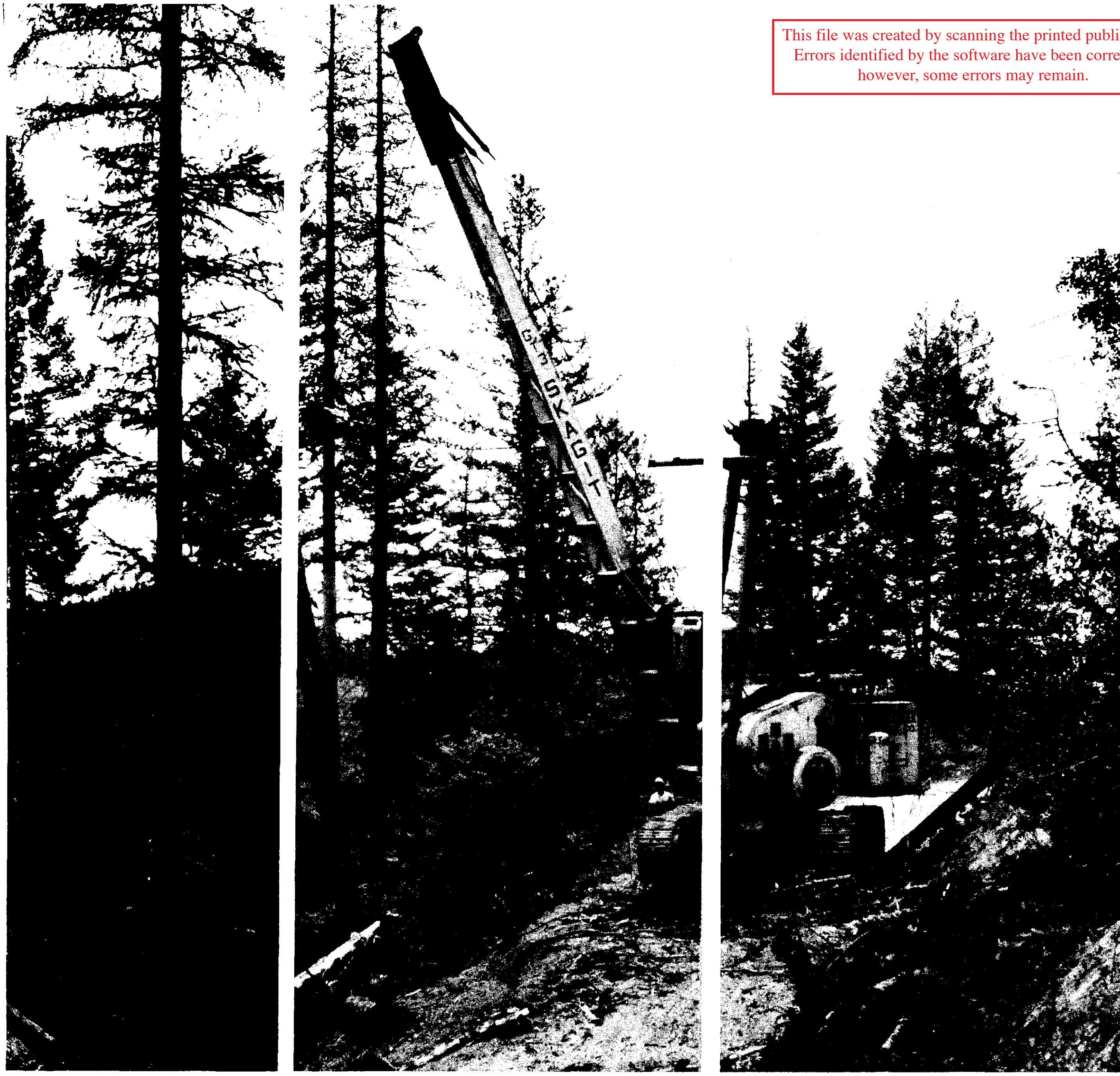

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NELLIE M. STARK

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Nellie M. Stark

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401

THE AUTHOR

Nellie M. Stark is a forest ecologist with the Montana Forest and Conservation Experiment Station, University of Montana, School of Forestry at Missoula, Mont. She has studied nutrient cycling in temperate and tropical forest ecosystem for many years. She is the author of the direct-cycling theory and also the concept of the biological "life" of soils--a means of evaluating the rate of deterioration of the productivity of soil.

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RESEARCH SUMMARY

Studies of the total amount of biologically essential nutrients removed in logs and water through clearcutting, shelterwood cutting, and group-selection cutting were conducted in a western larch (*Larix occidentalis*)/Douglas-fir (*Pseudotsuga menziesii*) forest at the Coram Experimental Forest near Glacier Park, Montana. Nutrient removal by species was investigated under three intensities of harvest. Results show that with the most intensive logging method (clearcutting) less than 0.25 percent of the total content of eight biologically essential cations in the effective root zone were removed with wood and bark. This means that intensive harvest took away an equivalent of 1/4 of 1 percent of the nutrients stored in the soil and rock of the root zone. In theory, it would require 28,000 years of clearcutting on a 70-year rotation to exhaust the total nutrients in the present root zone. Soil development will slowly extend the root zone downward. Far more important than total nutrients are those nutrients available in the soil. Harvest of wood and bark removed an equivalent of less than 14 percent of most of the available elements in the root zone. Harvest is a one-point-in-time removal of nutrients that have been accumulated in the wood and bark of trees over 70 years time. Removal of only 14 percent of what is at one moment available in the soil is a small loss. Unfortunately, we cannot yet measure the weathering rate so we cannot estimate how rapidly the removed nutrients will be returned through weathering. Harvest did remove from 14.8 to 91.7 percent of the available zinc in the soil (accumulated over +70 years). Although zinc is scarce in the parent material, this loss is not serious because sufficient zinc is still available for seedling growth. In most cases bulk precipitation alone will return all of the nutrients removed in harvest within 70 to 100 years. Nutrient losses from harvest on this relatively young, fertile soil is not a problem to management in the absence of erosion.

Nutrient levels in an intermittent stream were virtually unchanged by all logging treatments. The skyline system did not cause erosion. Because the area does not have a permanent stream or impermeable bedrock, it is unsuited to typical watershed study methods. Water samples taken below the root zone did show nutrient losses as a result of harvest, but these were at levels not significant to management. The most severe treatment studied, clearcutting by skyline and light burning, did not cause serious nutrient depletion from this forest ecosystem.

CONTENTS

INTRODUCTION

Modern logging methods are progressing toward complete utilization of wood fiber. With greater utilization comes increased removal of biologically essential nutrients. On rich soils, nutrient loss may do little harm, but on old or very young, poorly developed soils nutrient depletion caused by harvest may create either temporary nutrient shock or long-term nutrient deficiencies. In the case of nutrient shock (depletion of available nutrients), the soil contains adequate levels of biologically essential elements but they are in unavailable form. During shock, one or more of the essential elements is depleted from available form, and time is needed to allow weathering, precipitation, and organic decomposition to restore the available nutrient reserves. Long-term nutrient deficiencies result when not enough of one or more biologically essential elements remains in the root zone of the soil in either available or unavailable form to restore the soil to productivity (Stark 1977, 1978).

In western Montana, the greatest concern is for temporary nutrient depletion of young, undeveloped soils. Steep topography can accelerate nutrient loss through runoff, erosion, dust, or slump. In calculating nutrient losses resulting from harvesting, data are often not available for various species or different harvesting intensities.

This study has accumulated data on the elemental content of the harvestable portions of eight local tree species. Actual nutrient loss from the site was estimated from careful measurement of the volumes and weights of each species harvested. Harvest losses were related to the levels of available and total biologically essential elements in the soil to the limit of the root zone.

Land managers have also shown increasing concern over the possible loss of nutrients in soluble form from the root zone as a result of harvest. Erosion and solution losses below the root zone can detract from the ability of a soil to grow the next forest. Where logging activities approached streambanks too closely, there has been an increase in the sediment load and nutrients lost via streams. The Hubbard Brook study (Bormann and others 1968) showed the magnitude of nutrient loss associated with clearcutting. Few studies have attempted to quantify loss of soluble nutrients on drier western soils where the streams are intermittent and the bedrock fractured. Loss of soluble nutrients must be understood to allow ecologically sound land management.

Numerous studies have monitored the effects of logging and fire on stream water quality (Fredriksen 1971, Fredriksen and others 1975; Likens and others 1967; Moore 1974; Tiedemann 1974). Watershed studies are conventionally used to show changes in water quality as a result of treatment. But the stream studied in the Coram Experimental Forest is partly underground. It is ephemeral and the area does not have unfractured bedrock, making it unsuited to a conventional watershed study. For this reason, nutrient losses below the root zone were measured using lysimetry and tension soil water extractors. Nutrients lost below the root zone of a mature forest are almost as effectively lost to tree growth as if they were washed into a stream.

In 1973, the USDA Forest Service initiated a series of timber harvesting and utilization studies on the Coram Experimental Forest near Glacier National Park in western Montana (fig. 1). The overall objective of the project was to evaluate four levels of utilization and three silvicultural prescriptions, followed by burn and no-burn treatments, on the recovery of the above and below ground portions of the ecosystem. The study reported here, a portion of the total project, describes the impact of different levels of log removal and solution losses on the nutrient status of the ecosystem.

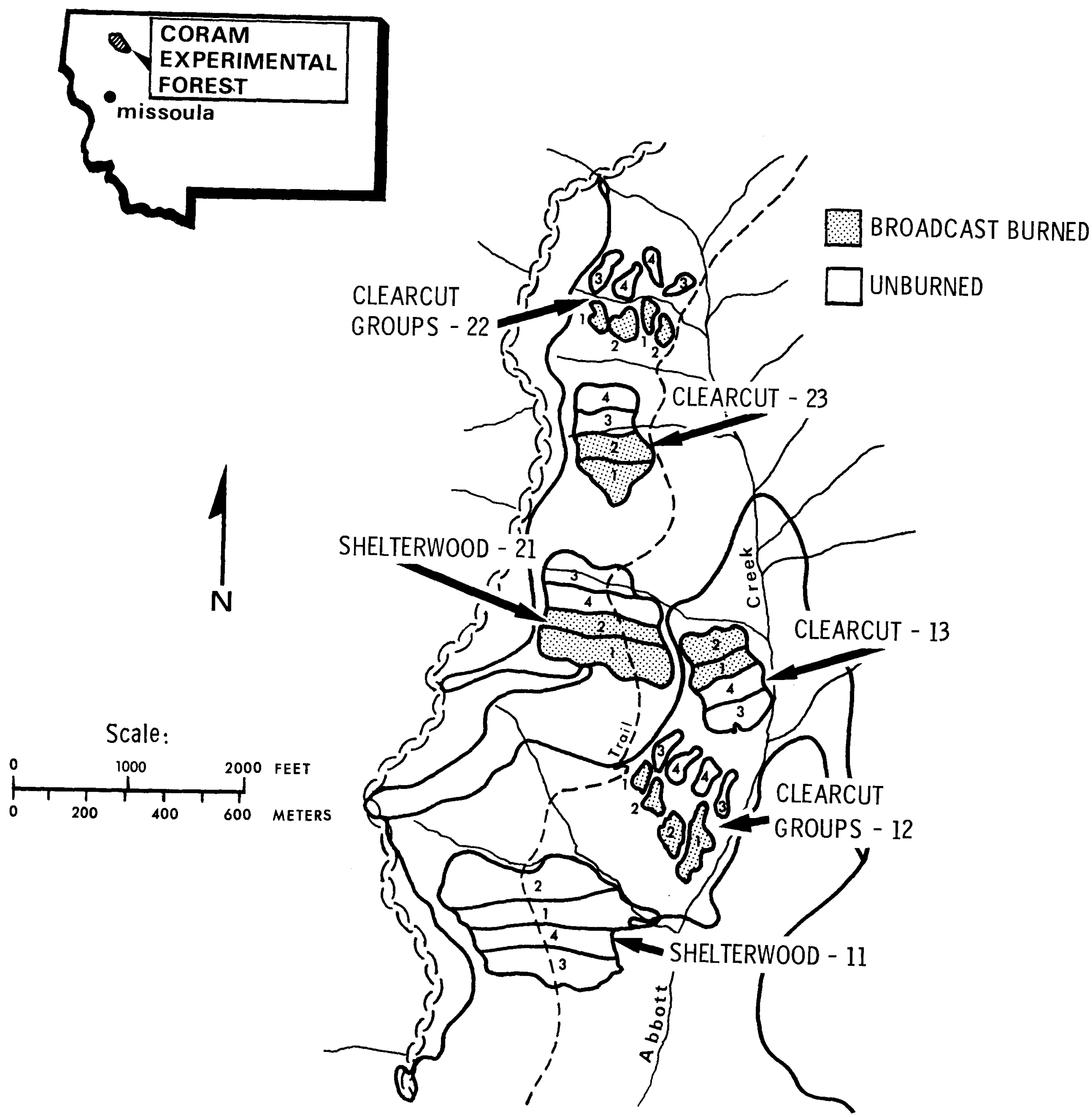

Figure 1.--Map of the Coram Experimental Forest logging study sites (from Artley and others 1978).

The treatments were designed to study the effects of different degrees of fiber utilization and burning 1 year after logging. The study involved 12 scientists and covered the period 1 year prior to logging (1973-74), logging (May-September 1975), burning (September 1975), and 2 years thereafter.

The forest is composed of larch/Douglas-fir (*Larix occidentalis* Nutt./*Pseudotsuga menziesii* [Mirb.] Franco) on steep slopes (35-45 percent) from 3,339 to 6,269 feet (1,018 to 1,942 m) elevation. The mean annual precipitation at the lower stations averages 31 inches (787 mm), with a mean annual temperature of 42.8°F (6°C). Much of the precipitation falls as snow. The snowpack lasts about 6 months. Appendix A includes a habitat type listing and a species listing for herbs and shrubs. Soils are derived from argillite, impure limestone, and quartzite, with some influence from glacial drift and in some areas volcanic ash (Klages and others 1976). Most are gravelly silt loams with up to 50 percent rock. Surface soil had a bulk density of 0.9 g/cm^3. The soils of the study area are primarily cryocrepts of the Felan series (possibly andeptic), and andeptic cryoboralfs, or eutroboralfs.

A portion of the main study included a complete inventory by the USDA Forest Service of all standing dead and live timber, as well as downed timber before and after harvest.[1] The difference constitutes the material removed from the site during harvest.

The silvicultural prescriptions included two replications of clearcutting, shelterwood, and group selection logged with a skyline yarding system. Treatments within each prescription were (descending order of intensity of utilization) as follows:

Silvicultural prescription	*Utilization standard*	*Remaining understory treatment*	*Postharvest site preparation*
Clearcut (CC) 1 and 2	1. Intensive log utilization (8 ft long, 3 in top, 2.4 m-7.6 cm) *all* trees live and dead.	Cut	Broadcast burn
	2. Conventional sawlog utilization of live and recently dead sawtimber.	Cut	Broadcast burn
	3. Heavy fiber utilization of all trees 1+ in dia. (2.54 cm), live and dead, including tops and branches 1+ in (2.54 cm).	Cut	None
	4. Intensive log utilization (8 ft, 3 in top, 2.4 m-7.6 cm) all sawtimber (7+ in dia., 17.8 cm), live and dead.	Uncut	None
Shelterwood (SW) 1 and 2	Same as for clearcuts for all categories		
Group selection (GS) 1 and 2	Same as for clearcuts for all categories		
Control (C) 1 and 2	Unlogged, unburned		

[1]Benson, R. E., and Joyce Schleiter. 1978. Volume and weight characteristics of a typical Douglas-fir/western larch stand. USDA Forest Service, unpublished report.

INFLUENCE OF LOGGING ON SOIL WATER NUTRIENTS

Methods

Skyline logging studies in Douglas-fir/larch forests at the Coram Experimental Forest in western Montana used clearcutting and shelterwood cuts, with three levels of utilization (reported here). Because the area does not have a permanent stream, nutrient loss was measured in the ephemeral Abbott Creek and through changes in the soil water quality below the root zone. The elements H, Ca, Cu, Fe, F, Mg, Mn, Na, NO_3, PO_4, and Zn were measured in soil and stream water, in precipitation, and throughfall whenever water was available before and after logging and 1 year after burning.

The study reported here covers only the nutrient cycling portion of the main research. Only the clearcut and shelterwood areas were studied for soil water quality and the fourth treatment (understory uncut, slash left, no burn) was omitted from consideration to focus attention on extreme treatments.

Changes in soil chemistry were studied by soil extraction using 0.002N H_2SO_4 and by soil water extracted from soil in the field using permanently placed tension extractors (Soil Moisture Corporation). Soil and water samples were from replicate plots on clearcutting and shelterwood treatments. Soil samples were obtained by digging a pit to 19.6 inches (50 cm) and removing 4,000 g soil samples at 0-3.9 inches (0-10 cm), 7.8-9.8 inches (20-25 cm), and 17.7-19.6 inches (45-50 cm) depth. The soil samples were then taken to the laboratory, sieved (1 mm), and 2 g subsamples were extracted with 0.002N H_2SO_4. The cations were analyzed on an atomic absorption spectrophotometer (Techtron AA-5). Phosphate was determined colorimetrically on the acid extract (Farber 1960). Soils were also tested for physical characteristics. Soil water samples were extracted from sites 3 feet (1 meter) from the soil pits (fig. 2) by placing a 1-1/2 inch (3.8 cm) plastic tube with a porous ceramic tip in a carefully augered 1-1/2 inch hole to 19.6 inches (50 cm). The porous ceramic tip was previously cleaned with acid and distilled water. The tip was seated in a slurry of mud from the bottom of the hole and sealed along the sides of the hole to prevent air leaks. After a period of 5-10 days for equilibration, the PVC tubing was sealed with a stopper and a vacuum was pumped on the tube, drawing soil water in through the ceramic tip. After 3-5 days, soil water was removed from the tubing using a clean pump and acid-cleaned Nalgene tubing and bottles. This water was taken in marked bottles to the laboratory for chemical analysis on the atomic absorption spectrophotometer and colorimeter.

The two methods, laboratory soil extraction and field soil water extraction, were used to compare results. Soil water removed under tension was by far the best indicator of changes in soil chemistry. The soil water is the solution in immediate contact with living roots and from which roots obtain nutrients. It is not an artificial extract. The soils vary greatly from point to point, so a soil water sample gives integrated results. Therefore, only soil water data will be reported here. Samples of soil water were withdrawn from above the tree root zone, within the tree root zone, and below the tree root zone whenever available soil water occurred. Fractured rock occurs at 19.6-21.7 inches (50-55 cm) depth. The data presented here represent the results from 200 soil water probes over 4 years. Bulk precipitation, stream water, and throughfall were collected from the same areas. Abbott Creek is ephemeral and partly underground, so it could not be used directly in evaluating nutrient losses from the treatments. It surfaces above one of the treated areas, and then goes underground below the clearcut and emerges near the shelterwood cuts. Changes on the slopes could be reflected in the stream, in spite of its ephemeral nature.

Figure 2.--Soil water probes set at three depths in the ground to collect soil water after the burns at Coram.

Water samples had to be frozen because of the distance between the laboratory and field study site. The samples were normally frozen for 1 week, thawed at room temperature, and analyzed by a Techtron AA-5 atomic absorption spectrophotometer for Ca, Cu, Fe, K, Mg, Mn, Na, and Zn (Techtron 1974). Subsamples were tested for pH, F, and NO_3 by specific ion analyzer, and PO_4 by the most sensitive stannous chloride method reported in Farber (1960). Data from other portions of the study were used to aid in the final interpretation. Because water samples could rarely be brought from the field in winter without freezing, it was impossible to measure bicarbonates.

Statistical tests compared the changes in the elemental content of soil water means:

1. By depths and treatments--total cations and anions

2. By year and treatments--total cations or anions

3. By silvicultural prescription and utilization standard--total cations or anions

4. By all three methods above for individual cations and anions

5. By control blocks versus test blocks and by test versus test blocks.

The F-statistic was used first to test for equal variances in each paired comparison. Where the variances were found to be equal, a regular t-test was used to test for the differences in the means; an "appropriate" t-test was used.

Results and Discussion

All results are expressed as significant at the 5 percent level. Data are reported for pretreatment (July 1973-April 1974, 237 collections), postlogging (May 1974-Sept. 1, 1975, 452 collections), and 1-year postburn (Sept. 1, 1975-June 30, 1976, 870 collections). About 510 collections were made in 1978.

The initial statistical tests showed that the replicates for each silvicultural prescription differed significantly in soil water quality so that the two clearcuts and two shelterwood treatments had to be considered separately. Comparisons were made between the test area and its nearest unlogged control (table 1). Appendixes B and C provide detailed soil physical and chemical data, which may be compared to soils elsewhere and which may be useful in management plans.

Table 1.--*Mean and standard deviation of total cations and anions in soil water after logging and after burning, Coram logging study (mg/ℓ)*

Study plot		Postlogging treatment			Postburn treatment		
		1	2	3	1	2	3
Total cations							
Control 1[1]	Mean	21.8	21.8	21.8	22.3	22.3	22.3
	SD	16.3	16.3	16.3	10.9	10.9	10.9
Control 2	Mean	7.1	7.1	7.1	9.0	9.0	9.0
	SD	3.2	3.2	3.2	3.9	3.4	3.9
Shelterwood 1	Mean	13.9	14.9	12.1	14.5	14.3	12.9
	SD	6.5	8.2	6.3	5.0	9.0	6.1
Shelterwood 2	Mean	19.4	9.2	15.1	17.3	10.8	11.4
	SD	10.2	4.4	15.6	7.5	5.3	9.1
Clearcut 1	Mean	17.2	34.3	19.6	25.1	41.5	22.1
	SD	10.7	26.7	12.8	13.5	28.4	17.6
Clearcut 2	Mean	17.3	7.9	11.9	17.2	16.2	11.9
	SD	10.7	4.9	6.7	11.9	11.9	6.7
Total anions							
Control 1	Mean	1.9	1.9	1.9	7.5	7.5	7.5
	SD	.9	.9	.9	5.2	5.2	5.2
Control 2	Mean	1.4	1.4	1.4	2.6	2.6	2.6
	SD	.6	.6	.6	4.9	4.9	4.9
Shelterwood 1	Mean	2.2	5.6	2.1	4.8	3.9	4.9
	SD	1.3	9.3	1.4	5.1	3.6	4.6
Shelterwood 2	Mean	1.9	1.3	1.3	6.4	7.1	3.8
	SD	.8	.7	.5	6.4	6.9	2.9
Clearcut 1	Mean	5.3	14.2	6.5	19.6	31.2	5.5
	SD	3.5	15.9	5.5	15.9	25.0	5.4
Clearcut 2	Mean	3.3	1.4	3.0	19.9	14.3	3.0
	SD	5.0	.5	2.6	19.4	12.3	2.6

[1]Controls 1 and 2 are the same plots for treatments 1, 2, and 3. Treatment 1 = heavy log utilization, light burn, Treatment 2 = conventional utilization, medium burn, Treatment 3 = heavy fiber utilization.

Shelterwood Logging--Cation Losses

The total cations in the soil water for shelterwood 1 were lower 1 and 2 years postlogging when compared to the closest control. Shelterwood 2, which was about 0.31 miles (0.5 km) from shelterwood 1, had higher cation levels in the soil water for treatment 1 postlogging, and treatments 1 and 2 (light and hot burns) postburn (table 1). The total soil water cations in shelterwood 1 probably result from unusually high levels of ions in the soil water of the control, which had unusually deep litter. Shelterwood 2 behaved more as expected (table 1), with higher cation loadings in the postlogging and postburn soil, compared to its nearest control (control 2, table 1). Standard deviations are sometimes high because data cover a full year's seasonal variation.

Clearcut Logging--Cation Losses

Clearcut 1 was the only block where a moderately hot burn treatment was possible. It produced a significant increase in the soil water cations, compared to its closest control (1). Logging left considerable needle debris on the slopes, which produced postlogging increases in the soil cations of clearcut 1, and postburn increases from nutrients added from ash. Clearcut 2 had higher total cation levels in the soil water following logging where the slash was removed and later burned (treatment 1) and where it was removed and not burned (treatment 3) but not in treatment 2. The removal of slash left a large amount of fine needle debris so that all sites had abundant fungal growths during the winter under the snow, regardless of whether the coarse slash (3 in, 7.6 cm) was removed or not. After burning, clearcut 2 had higher soil cation levels than its control for all treatments, heavy and light burning, and no burning (table 1).

Shelterwood Logging--Anion Losses

The total anions in the soil water of shelterwood 1 were higher 1 year postlogging on the heavy slash site (treatment 2, table 1), but lower than the control 2 years postlogging. In the case of shelterwood 1, "postburn" actually means 2 years postlogging, because this block was never burned. Shelterwood 2 was burned, and showed high levels of anions in the light burns but not the hot burns (postburn) and only in the heavy slash loading postlogging (compared to controls). High anion levels on the high utilization unburned site must come from the decay of excess needles.

Clearcut Logging--Anion Losses

Clearcut 1 had significantly higher levels of total anions in the soil water (mostly NO_3^-N) following logging in all three treatments, compared to the soil water from controls. This means that slash decomposition during the first year following logging resulted in an unusually high rate of nitrate release relative to the controls. Postburn, the anions were high in treatments 1 and 2 (light and heavy burns). Clearcut 2 showed elevated levels of anions only in treatment 3 (slash removed), but in all three treatments postburn (table 1). The main anion is again nitrate.

Total Cation and Anion Losses by Slash Treatment

The effects of the three slash treatments on total soil water cations can be seen by comparing treatment means within years. For total cations, all depths combined, treatment 1 (slash removed, burned) was different from treatment 2 (slash left, burned) in four out of eight possible cases. Treatments 1 and 3 differed in two out of eight cases, and treatments 2 and 3 differed significantly in three out of eight cases.

No one treatment produced predictable increases in soil water cations in more than 50 percent of the tests. This is partly the result of the moderate disturbance of the site from the logging method (skyline) and the relatively low burning temperatures (138°F, 59°C).

The total anions differed significantly between treatments 1 and 2, and treatments 1 and 3 four out of eight times (each) and between treatments 2 and 3 in six out of eight cases. The heavy burn did produce significant increases in the anions and particularly nitrate in soil water.

Results by Individual Ions

The analysis of the results for individual ions requires considerable space, therefore only a few main points will be presented in a year-to-year comparison. The elements NO_3, Mg, Cu, Na, Zn, and Mn were those most often influenced by logging and burning (table 2). Those most influenced by burning alone were NO_3^-, Cu, Mg, Mn, K, Fe, Zn, and PO_4. Those least influenced by the treatments were Ca, F, and Fe. These are strongly dependent on an acid soil solution for solubility. In most cases the alkali added to the soil through burning was inadequate to cause a greater increase in soil alkalinity as had occurred in a previous study (Stark 1977). If the burns had been hotter than 572°F (300°C), these elements, and particularly Fe, should have been significantly altered by the burning. The average ion concentrations in soil water are shown in table 3.

Table 3 shows the average levels of cations and anions present in soil water before logging and after burning. Unfortunately, during 1973-74, or prelogging, no data could be obtained from shelterwood 2, clearcut 2, and control 2. These results summarize the effects of increasing utilization for all four areas compared to the two controls (table 3). Most elements in the soil water do not show drastic differences between prelogging and postburn samplings. There is a tendency toward more NO_3^-N and PO_4 after burning, but only in a few cases are the differences great. Significant differences that appear in the raw statistics may not appear in these summaries. The summaries are included to show the low magnitude of chemical differences in soil water resulting from logging and light burning.

Shelterwood cutting caused the greatest changes in phosphate with the most important differences between postlogging and postburn treatments 1 and 2 for shelterwood 2. Shelterwood 1, which was not burned in 1975, had almost no significantly different soil water ion concentrations 2 years postlogging.

Clearcutting showed no definite pattern of elemental differences in the soil water following logging, but treatments 2 and 3 were most different (by seven elements on clearcut 1, but not on 2). Burning produced significant differences in 10 ions between the medium burn (treatment 2) and slash removal (treatment 3) postburn for clearcut 1 but not for 2. Clearcut 1 generally burned much hotter than did 2.

Ionic differences by depth were most prominent between 7.9-9.8 inches (20-25 cm) and 15.7-19.6 inches (40-50 cm) when all 3 years were considered collectively. This is surprising because the burning and logging should have caused the greatest change at 0-3.9 inches (0-10 cm). The importance of deep soil differences in ion content suggests a spotty but widespread influence of scattered limestone deposits beneath the soil surface.

The means in tables 1 and 3 are figured on a slightly different number of sample points, so they do not agree exactly.

Table 2.--*Summary of results of year-to-year statistical tests, combining means for all soil depths and separating silvicultural practice, level of utilization, and site preparations*

Year[1]	Ca	Cu	Fe	F	K	Mg	Mn	NO_3	Na	PO_4	Zn	Cations	Anions
	Element												
Years 1 vs 2													
Control 1		*[2]		*		*	*		*				
Shelterwood 1													
Heavey log util. light burn													
Conv. log util. med. burn			*			*	*	*	*		*	*	
Heavy fiber util.-no burn						*	*		*	*	*	*	
Clearcut 1													
Heavy log util. light burn													
Conv. log util. med. burn	*	*		*				*	*		*	*	
Heavy fiber util.-no burn		*	*			*		*	*		*		
Control 2													
Shelterwood 2													
Heavy log util. light burn													
Conv. log util. med. burn													
Heavy fiber util.-no burn													
Clearcut 2													
Heavy log util. light burn		*	*			*	*	*	*				
Heavy fiber util.-no burn													
Year 1 vs 3													
Control 1													
Shelterwood 1													
Heavy log util. light burn													
Conv. log util. med. burn	*		*			*	*			*	*	*	*
Heavy fiber util.-no burn		*				*	*	*	*	*			

See footnotes at end of table.

(Cont.)

Table 2.--*Summary of results of year-to-year statistical tests, combining means for all soil depths and separating silvicultural practice, level of utilization, and site preparation--Continued*

Year[1]	Element												
	Ca	Cu	Fe	F	K	Mg	Mn	NO_3	Na	PO_4	Zn	Cations	Anions
Clearcut 1													
Heavy log util. light burn													
Conv. log util. med. burn	*		*	*	*	*		*	*	*			
Heavy fiber util.-no burn		*	*	*		*		*	*	*	*		
Control 2													
Shelterwood 2													
Heavy log util. light burn													
Conv. log util. med. burn													
Heavy fiber util.-no burn													
Clearcut 2													
Heavy log util. light burn													
Conv. log util. med. burn													
Heavy fiber util.-no burn													
Years 2 vs 3													
Control 1					*	*	*	*	*				
Shelterwood 1													
Heavy log util. light burn		*	*		*			*		*			
Conv. log util. med. burn										*			
Heavy fiber util.-no burn		*						*		*	*		
Clearcut 1													
Heavy log util. light burn		*	*		*	*		*		*		*	
Conv. log util. med. burn		*	*		*	*		*					
Heavy fiber util.-no burn		*							*				

See footnotes at end of table

(Cont.)

Table 2.--*Summary of results of year-to-year statistical tests, combining means for all soil depths and separating silvicultural practice, level of utilization, and site preparation--Continued*

Year[1]	Element												
	Ca	Cu	Fe	F	K	Mg	Mn	NO_3	Na	PO_4	Zn	Cations	Anions
Control[2]	*	*						*			*		
Shelterwood[2]													
Heavy log util. light burn		*				*	*	*	*				
Conv. log util. med. burn					*	*	*	*	*				
Heavy fiber util.-no burn		*		*			*	*	*				
Clearcut[2]													
Heavy log util. light burn		*	*			*	*	*	*		*		
Conv. log util. med. burn	*				*		*	*		*			
Heavy fiber util.-no burn		*				*		*	*		*		

[1]Year 1 - prelogging,
Year 2 - postlogging,
Year 3 - postburn.
[2]* indicates a significant difference at the 5 percent level.

Table 3.--*Average elemental content of Coram soil water by silvicultural treatment before logging (1973-74) and after burning (1975-76)*

Block	Treatment	$H^+ \times 10^{-6}$	Element											Total	
			Ca	Cu	Fe	F	K	Mg	Mn	NO_3	Na	PO_4	Zn	Cations	Anions
Prelogging															
Shelterwood 1	2	--	9.8	0.04	0.25	0.09	4.9	2.1	0.06	3.6	--	0.33	0.04		
	3	--	7.5	.03	.16	.10	3.4	2.1	.02	1.8	--	.23	.03		
Clearcut 1	2	--	12.3	.04	.15	.18	7.2	2.4	.03	5.4	--	.54	.04		
	3	--	12.9	.03	.27	.09	2.9	1.8	.02	2.9	--	.29	.04		
Control		--	14.2	.03	.19	.12	3.5	1.9	.02	2.5	--	.13	.03		
One Year Postburn															
Shelterwood 1	1	0.10	8.1	.06	.17	.15	4.4	1.7	.01	3.5	0.8	.94	.03	15.3	4.6
	2	.10	7.1	.03	.16	.09	4.2	1.5	.01	2.9	.8	.62	.03	13.7	3.6
	3	.09	8.3	.04	.12	.16	3.9	1.7	.01	4.4	.9	.49	.03	15.0	5.1
Shelterwood 2	1	.15	7.7	.06	.12	.11	7.2	2.5	.04	5.0	1.0	.74	.04	18.7	5.8
	2	.17	4.2	.04	.13	.06	4.7	1.4	.04	5.9	.6	.53	.02	11.2	6.5
	3	1.90	6.5	.04	.13	.10	3.6	2.3	.18	3.0	.6	.54	.03	13.3	3.7
Clearcut 1	1	.08	15.0	.04	.08	.38	5.2	2.3	.01	16.9	.7	.87	.02	23.4	17.9
	2	.03	24.3	.03	.04	.64	12.5	4.2	.01	28.6	.7	.75	.02	41.9	29.6
	3	.06	16.3	.04	.16	.31	2.2	2.1	.01	5.1	.5	.37	.03	21.4	5.7
Clearcut 2	1	.13	8.9	.05	.15	.08	5.9	2.5	.01	16.7	.7	.81	.06	18.3	17.6
	2	5.00	7.9	.05	.13	.21	5.5	1.8	.16	12.8	.8	.80	.05	16.3	13.8
	3	.39	5.3	.05	.14	.09	4.0	1.3	.01	6.8	.5	.55	.04	11.3	7.4
Control 1		.05	13.8	.04	.13	.12	5.0	2.4	.005	6.3	.8	.37	.02	22.2	6.8
Control 2		.35	4.7	.06	.19	.09	2.2	1.0	.009	2.3	.6	.27	.03	8.8	2.6

Ionic Differences in Soil Water by Years

The total cations in the soil water showed few significant differences by year, but the total anions were significantly different between years 2 and 3 (logging and burning) in shelterwood 1, 10 out of 14 plots. Copper, potassium, magnesium, nitrate, sodium, and phosphate were the ions most influenced by burning between years 2 and 3. Logging, as measured by ion changes between years 1 and 2, produced fewer ionic differences than did burning. Those ions most affected by logging (based on annual comparisons) were F, Mg, Mn, NO_3, Na, and Zn. These were probably released from extremely active needle decay during the winter.

The exceedingly dry summer of 1977 complicated this study. Only a very few soil water samples could be extracted at all, and these were taken in the early spring. So few samples of soil water are available from 1977 that it is impossible to tell anything about nutrient movement for that year. It is quite certain that very little water or nutrients moved below the root zone in 1977.

In 1978, more than 450 soil water samples were collected during the spring. For purposes of comparison, data were taken from the months of May and June for 1978 and compared to data from May and June of 1976, the last year with collectable soil water. Data were combined for all depths within treatments for each block studied. Results are summarized in the following tabulation:

Block	*Treatment*	*Significant ion*	*Year with greater quantity*
Shelterwood 1	Unburned	Ca	78
	Light fuel	Cu	78
		Zn	78
Shelterwood 1	Unburned	Cu	78
	Heavy fuel	Fe	78
		F	78
		NO_3	76*
		Zn	78
Shelterwood 1	Heavy utilization	Cu	78
	No burn	Fe	78
		F	78
		NO_3	76*
		Zn	78
Clearcut 1	Heavy fuel	Cu	78
	Burned	Fe	78
		F	78
		NO_3	76*
		Zn	78
Clearcut 1	Heavy utilization	F	78
	Unburned	K	76
		Mn	76
		NO_3	76*
		Na	76
Control 1	No treatment	Cu	78
		F	78
		NO_3	76*
		Zn	78

Continued

Block	*Treatment*	*Significant ion*	*Year with greater quantity*
Shelterwood 2	Light fuel Burned	Fe	78
		F	78
		NO_3	76*
		Zn	78
Shelterwood 2	Heavy fuel Burned	Ca	78
		Cu	78
		Fe	78
		F	78
		NO_3	76*
		Zn	78
Shelterwood 2	Heavy utilization	Cu	78
		Fe	78
		F	78
		Mn	76
		NO_3	76*
		Na	76
		Zn	78
Clearcut 2	Light fuel Burned	Fe	78
		F	78
		NO_3	76*
		PO_4	76
Clearcut 2	Heavy fuel Burned	Fe	78
		F	78
		Mn	76
		NO_3	76*
		Zn	78
Clearcut 2	Heavy utilization	Ca	78
		Fe	78
		F	78
		Mg	78
		NO_3	76*
		Na	78
		Zn	78
Control 2	No treatment	Ca	78
		Cu	78
		F	78
		Mg	78
		Mu	78
		Zn	78

*NO_3 consistently higher in 1976.

These results are extremely difficult to interpret because the 1978 soil water represents those nutrients freed from the surface and through weathering in 1977 and in 1978, minus what was taken up by plants. Normally, nutrient status is best evaluated year by year, but this is impossible with this method in dry soil. Theoretically, low available soil moisture during the growing season in 1977 should mean abnormally low nutrient uptake from the soil and slow growth. Increment borings of trees in the area do verify slow growth for 1977, but there is no proof of low uptake. If the roots did not take up their "normal" amount of water and nutrients in 1977, then there would be a natural excess of nutrients in available form at the start of 1978. These extra nutrients would appear in the extracted soil water in 1978 and we would not know if they were "a leftover excess" from 1977, or if they truly resulted from the treatments applied.

Soil moisture in July of 1977 was 7.8 percent and only 8.4 percent in the wettest period of the summer. Based on the -1/3 and -15 bar moisture contents for these soils, a summer moisture percentage of 7.8 percent would allow little or nothing for plant uptake and growth in July. Thus, most nutrient and water uptake had to occur in May and June of 1977. The trees apparently lost 1.5 months of growth water in 1977. From these results, it is fair to say that some nutrients were left in the soil after the 1977 growing season in excess of the "usual" levels after a full growth period. High nutrient levels in 1978 would be expected under these conditions. We still do not know for sure if nutrient levels were elevated in 1978 because of treatment inputs or not. The magnitude of differences in means from 1976 and 1978 is small enough to suggest that if treatment was also causing higher soil water nutrient levels, it was probably not a major addition of great significance to management. In a few cases the means for individual ions in the 1978 soil water were two to three times higher than for 1976, but in the majority of cases, the difference of means was much lower. Copper and zinc were often two or more times higher in the soil water in 1978 as compared to 1976. Because this difference appears in the control plots also, it is likely that the increase in these ions in soil water is the result of some widespread release after the soil became moist again and not of the treatments alone.

Not all ions were higher in 1978 than in 1977. Potassium and magnesium were only higher in a few cases. Potassium did not show up as significantly higher (5 percent) in the 1978 soil water from any of the hot or lighter burns, suggesting that burn treatment effects had disappeared. Sodium was higher in 1978 than in 1976 in only 3 out of 14 plots. Copper and zinc were higher in 1978 soil water in 8 out of 14 plots; zinc, in 11 out of 14 plots, respectively. PO_4 was highest in 1978 soil water in only 1 out of 14 plots (clearcut 2, light burn).

Nitrate was higher in 1976 soil water compared to 1978 soil water in 11 of 14 plots. Nitrate was often two to five times higher in 1976 than in 1978, which suggests treatment effects forcing the soil nitrate levels higher in 1976. Because nitrate is the only ion that is produced in the soil mainly by microbial activity, it could be expected to behave the opposite of ions weathered from rock. Ion release from organic matter is all microbial, but additions of nitrate to the system are dependent on both temperature and moisture. It is likely that the low soil moisture in 1977 resulted in less nitrogen fixation than would occur in a wetter year. Thus, the soil water would be readily depleted of available NO_3^--N in 1978 when active plant growth began. Only the light burn area in clearcut 1 showed no significant ion differences in soil water between 1976 and 1978. Control 2 showed 6 out of 10 ions higher in 1978 than in 1976, again suggesting that these high ion concentrations were the result of drought rather than the treatments. Control 1 had fewer significant ions in the 1978 soil water as compared to control 2, but control 1 had much less litter and different soil moisture conditions than occur at higher elevation.

In general, the effects of logging and fire appear to be small 4 years after logging and 3 years after light burning.

Clearcutting had a greater impact on soil nutrients than did shelterwood cutting, although neither produced massive or serious nutrient losses. Burning, as expected, increased the concentration of most ions in the soil water, especially Cu, K, Mg, Na, NO_3, and PO_4. The low intensity of the burns did not significantly reduce soil water iron, as is known to occur in hot burns (Stark 1977). Logging temporarily increased soil water levels of F, Mg, Mn, NO_3, Na, and Zn. This is the result of the rapid winter decay of a heavy green needle loading on the surface of the soil following logging. Slash removal often did not reduce soil water ion concentrations because wood to 3 inches (7.6 cm) was mainly removed, leaving behind large quantities of fine branches and needles. The needles began decaying under the snow during the first winter, whereas the recently cut heavy wood would release very few nutrients during the first winter.

Direct analysis of soil water is a more reliable indicator of short-term changes in soil water chemistry, than are artificial soil extraction procedures.

In this ecosystem, total nutrient losses beyond the reach of roots were insignificant. The data suggest that minimal surface disturbance by skyline logging does not cause excessive nutrient losses from the ecosystem. Although clearcutting influenced soil water quality more than did shelterwood cutting, neither produced serious nutrient losses. Burning increased soil water ion loads for a year, but the generally low-intensity burns prevented massive nutrient losses below the root zone. A full evaluation of nutrient losses from harvest and slash treatment requires measurements of the nutrients removed in harvested wood and bark. These measurements are being reported separately. The study demonstrates that logging and slash disposal as practiced here are not damaging in terms of excessive soil nutrient losses beyond the root zone or through overland flow into streams. Different results can be expected with different, more erosive soils or logging methods that disturb the surface soil.

Abbott Creek

Abbott Creek runs underground for 0.12 mile (0.2 km) and may dry up or disappear in late summer. Samples taken from above and below the treated areas actually showed a reduction in ion content, which is probably the result of 0.12 mile (0.2 km) underground transit. For this area, a watershed-type study was impractical. For a week postburn, there was a slightly elevated level of ions in the creek, but statistically not significant. Other studies involving cutting have shown considerable export of nitrogen and other ions in stream water on watersheds with impermeable bedrock (Bormann and others 1968).

INFLUENCE OF WOOD REMOVAL ON NUTRIENT CYCLING

Methods

To estimate how much of the biologically essential nutrients were being removed from the site as a result of harvest, it was necessary to analyze wood and bark in their naturally occurring proportions. All three silvicultural treatments were studied in duplicate, and all utilization treatments except the heavy utilization treatment, which included wood, bark, needles, and branches.

During harvest, wood and attached bark were collected from eight tree species, living and dead, using increment borings and cross-sections. Nutrient removal was based on the weight of bole wood removed. Volumes of wood removed per plot by species were converted to weight (kg) of wood and bark removed.

All plant samples were dried at 149°F (65°C), finely ground to under 0.069 inch (1 mm) and ashed in a muffle furnace at 977°F (525°±5°C) for 2 hours (Jackson 1958). The elements Ca, Cu, Fe, K, Mg, Mn, Na, and Zn were analyzed by atomic absorption spectrophotometry (Techtron 1974) and phosphate was measured by colorimetry (Jackson 1958). Total nitrogen was measured by the modified microKjeldahl procedure (Hesse 1972).

Over a period of three summers, duplicate soil extractions were made from the study site on 600 samples each year, using 0.002N H_2SO_4 extractant and measuring the same elements as were analyzed in plant samples. Two hundred soil and rock samples were also digested in HF-$HClO_4$ to determine total elemental content of the root zone. The percentage of rocks and the depth of the root zone were determined in the field. In addition, 500-800 soil water samples were extracted each year using soil moisture probes under tension, and were analyzed on the atomic absorption spectrophotometer with bulk precipitation, throughfall, and stream water for the same elements. An Orion specific ion analyzer was used for H^+, F^-, NO_3^-N, and a colorimeter for PO_4^-P by the most sensitive method for water (Farber 1960). These data constitute more than 300,000 measurements and are reported briefly in the first portion of this paper. They were used in calculating the actual amount of each element removed from the ecosystem during harvest.

Results and Discussion

The site index for western larch is 65 (SI 50-70, 50 years; Ray Shearer, personal communication, Forestry Sciences Laboratory, Missoula, Mont.) for the area and is reasonably uniform so that greater diameter usually means greater age. Wood of the same species varied considerably in elemental content with age and diameter (table 4). Sampling from increment borings made it possible to analyze the proper proportion of wood to bark for each diameter class. Elemental differences with size were the result of thicker bark with age, changing wood/bark ratios, and progressive storage of waste products in older wood. Often wood in the 6-12 inch (15.2-30.5 cm) size class was lower in elemental content than either the younger or older wood although there were exceptions (table 4).

Generally, western white pine (*Pinus monticola* Dougl.) and western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) were low in calcium and copper compared to the other species (table 4). Harvest of alpine fir (*Abies lasiocarpa* [Hook.] Nutt.) and Engelmann spruce (*Picea engelmannii* Parry) wood and bark would remove the most calcium from the site (table 4). Alpine fir, Douglas-fir, western hemlock, and western larch were the highest in phosphorus. Engelmann spruce and western larch had relatively high levels of zinc while western redcedar (*Thuja plicata* Donn.) wood plus bark was low in zinc. Harvesting the wood of alpine fir and Douglas-fir would remove more nitrogen than would harvest of other tree species. The most magnesium would be lost in the wood and bark of Douglas-fir, western hemlock, and western white pine. Alpine fir, Douglas-fir, and Engelmann spruce wood and bark were high in potassium (table 4). Potassium is usually low in supply in western forest soils.

Obviously, harvesting practices cannot be built around those species that are lowest in total elements removed with wood and bark, but a knowledge of relative nutrient losses by species can be important if the site to be harvested is extremely low in the available form of one biologically essential element and the species to be removed contains high levels of that element. Figure 3 shows the lower group selection (left) clearcut (right) after logging.

Table 5 shows how much merchantable wood was removed from each silvicultural prescription and treatment. The amount removed is a function of the density and size of the original stocking, and the intensity of utilization. The data represent a summation of volumes of all species present. Nutrient removal was based on the species components of the total volumes. Shelterwood cuttings removed from 576 to 2,950 ft^3/acre, while group selection cuts removed from 5,765 to 12,254 ft^3/acre.

Table 4.--*Average elemental content of bark plus wood for live commercial wood from the Coram Experimental Forest*

Species	D.b.h. class		Element										Ash
			Ca	Cu	Fe	K	Mg	Mn	N	Na	P	Zn	
	Inches	*cm*	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -	*μg/g*	- - - - - -	- - - - - -	- - - - - -	- - - - - -	*Percent*
Alpine fir[1]	< 6	<15.2	3406	9.1	72	1003	227	152	1089	29	527	12.1	1.5
	<12	[2]<30.5	3138	10.6	28	738	16	111	1610	25	659	8.4	1.0
	>12	>30.5	2467	9.2	39	1126	27	123	2602	20	406	10.2	0.9
Douglas-fir	< 6	<15.2	2100	9.6	29	1022	234	93	1208	21	716	14.5	0.5
	<12	<30.5	1125	7.7	17	305	394	43	884	18	657	9.3	0.6
	>12	>30.5	1586	9.3	26	517	91	71	1374	24	669	12.1	0.5
Engelmann spruce	< 6	<15.2	2100	8.8	179	878	137	81	805	20	323	21.4	1.2
	<12	<30.5	3330	9.0	36	1000	163	77	1009	22	473	23.9	0.8
	>12	>30.5	2900	10.9	24	933	126	115	653	30	454	11.3	0.9
Lodgepole pine	< 6	<15.2	1000	8.7	11	345	22	120	700	19	288	11.0	0.5
	<12	<30.5	1800	8.9	24	330	22	140	560	20	152	11.5	0.7
	>12	>30.5	777	5.8	31	253	185	75	630	28	310	11.6	0.5
Western larch	< 6	<15.2	1415	8.7	39	699	180	167	1176	24	673	12.7	0.8
	<12	<30.5	1071	9.5	56	374	64	71	607	17	486	42.4	0.6
	>12	>30.5	1186	9.0	33	392	132	81	476	23	350	9.6	0.2
Western white pine	< 6	<15.2	955	6.4	33	201	240	42	602	30	155	11.5	0.2
	<12	<30.5	765	5.9	37	270	170	31	607	25	149	7.4	0.2
	>12	>30.5	848	5.8	26	230	212	67	553	33	164	8.3	0.2
Westerm hemlock	< 6	<15.2	913	6.6	29	403	232	190	700	33	765	6.0	0.5
	<12	<30.5	783	6.3	36	423	174	153	707	36	541	5.6	0.5
Western redcedar	< 6	<15.2	1450	7.0	31	257	128	5	784	30	132	2.4	0.6
	<12	<30.5	1034	5.2	35	223	91	4	898	26	218	3.0	0.6

[1]See Appendix A for scientific names.

[2]The size category <30.5 cm (12 inches) covers samples from wood + bark from 15.2 to 30.5 cm (6-12 inches) in diameter.

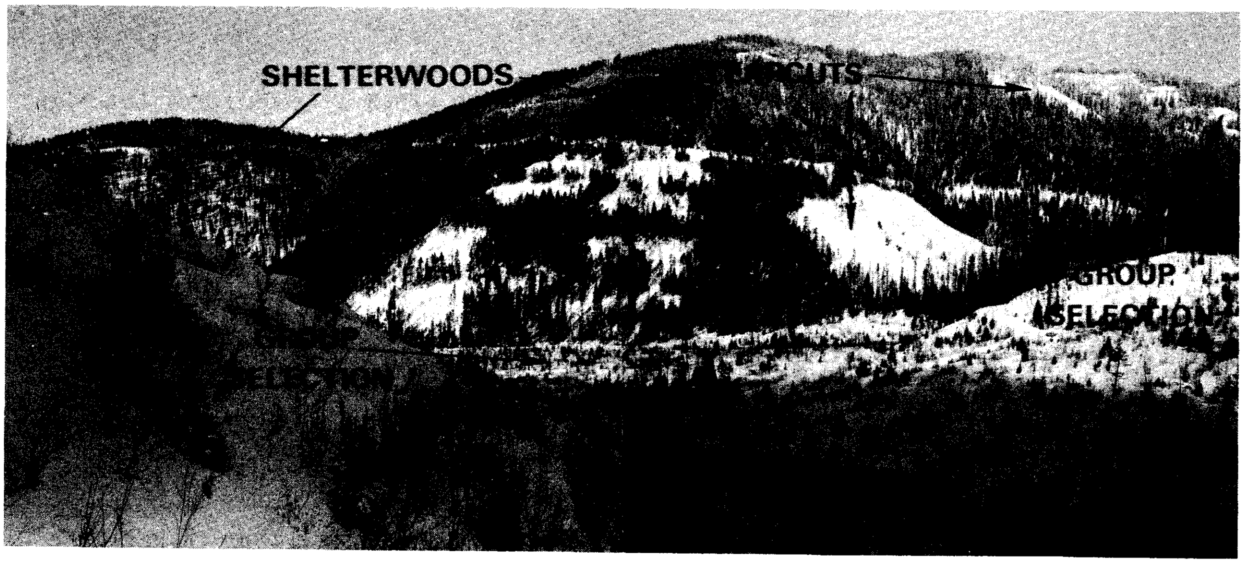

Figure 3.--Lower group selection cut (left) and clearcut block (right) at the Coram Experimental Forest after logging. A portion of the upper clearcut shows in the upper right hand corner.

Table 5.--*Total volume of wood 3-inch diameter and larger (7.6 cm) apparently removed in harvest*[1]

Block	Treatment			
	2	1	4	3
	Cubic feet			
Shelterwood 1	1,248	2,876	1,614	2,950
Group selection 1	5,765	7,586	8,607	7,655
Clearcut 1	4,323	6,426	5,895	4,962
Shelterwood 2	576	2,773	1,013	2,570
Group selection 2	12,254	6,214	9,009	6,241
Clearcut 2	4,519	6,387	4,035	3,533

[1]Derived by subtracting postharvest volume from preharvest volume, Benson and Schleiter (review draft). See tabulation for treatment definitions.

The data provide a rough estimate of the amount of nutrients likely to be removed with the three silvicultural prescriptions on these habitat types for mature forest.

Elemental losses from harvest can be evaluated in terms of the levels of available elements in the soil, or the available plus potentially available elements in soil, or the total elemental content of the ecosystem (soil + plants + animals + precipitation). Ideally, harvest losses should be evaluated against total ecosystem nutrient levels (available and stored, separately). This is a difficult comparison because of the problem of measuring animal biomass and elemental content on a unit area.

Data presented cover losses from logs only and do not reflect the losses from intensive fiber utilization. The calculations of nutrient loss from harvest relative to the total biologically essential elemental content to the limit of the root zone were based on a meter square surface area to the depth of 19.6 inches (50 cm), with a bulk density of 1.92 g/cm^3 (includes coarse rock fragments, not a typical andic soil).

The soils have moderate reserves of total calcium (5,240 g/0.5 m^3 root zone) but high levels of total iron (29,731 g/0.5 m^3), and high levels of potassium (19,573 g/0.5 m^3, table 6). Calcium and magnesium are the macroelements that are in shortest supply and most vulnerable to ultimate depletion. Phosphorus is quite low (1,621 g/0.5 m^3). The sampling sites did not include the calcareous material that underlies part of the Coram Experimental Forest.

In terms of available elements, calcium is relatively abundant (857 g/0.5 m^3), indicating that it is being readily released from the parent material and could easily be lost (table 6). Magnesium is available in low amounts (89 g/0.5 m^3) relative to calcium. Copper losses were high on a percentage basis because total soil copper is low. Low amounts of potassium (171 g/0.5 m^3) and iron (30 g/0.5 m^3) are available in the root zone. Phosphate (as PO_4^-P) is available in large amounts relative to its total content in the soil as P (table 6).

Table 7 shows the amount of each element removed from the site through harvest, divided by the total elemental content (available + potentially available) of the soil expressed as a percent. The four treatments are discussed under the Introduction, but data are relative to log removal only (merchantable and unmerchantable dead and alive). These results show that clearcutting and group selection removed the most cations relative to the total potentially available cations in the soil (0.18-0.21 percent, table 7). Clearcutting removed total cations amounting to from 0.05 percent to 0.18 percent of all the measured essential cations stored in the soil. Shelterwood cutting removed from 0.03 percent to 0.17 percent of the total soil cations (eight of biological importance). In terms of the total cation content of the soil, clearcutting of the type of CC1 or group selection cuts of the type on GS2 removed the most cations relative to the soil total content. In absolute terms, neither of these logging methods produced serious nutrient losses in wood plus bark if viewed as a single treatment on a 70- to 100-year rotation.

The largest cation losses for CC2 and GS2 occurred in treatment 1 where trees were removed down to 3 inches d.b.h. (7.6 cm) and the understory was cut. Treatment 2 produced the largest total cation losses for SW1 and GS1. On clearcut 1, treatment 4 removed the most total cations (relative to total root zone cations). More total biomass was removed in treatment 3 than in 1. Treatment 3 included the removal of needles and branches, but no data are available at this time on the weights of slash removed (only bole wood), so that nutrient loss from slash removal is not reflected in the data. The actual losses of ions from any one site varied according to the intensity of harvest, the original species present, and stocking, so that similar treatments did not show the same cation losses.

Harvesting wood + bark produced low percentage losses of Fe, K, Mg, Na, and Zn (table 7). These elements were either low in the materials harvested or high in the soil in total content. Calcium losses were only 0.2 to 1.7 percent of the total calcium, so that little harm was done to this relatively scarce ion (total) from harvest. Magnesium losses were even lower (0.02 to 0.23 percent) than those for calcium. Even the phosphorus removed in wood was low (0.2 to 1.2 percent of total soil P) and of no serious immediate concern. On the basis of total elemental content, none of the logging methods or intensities used produced significant losses of essential cations from the total ion reserve in the soil through removal of wood or bark. A 0.2 percent loss of the essential cations means that 70-100 year rotations could continue for 28,000 to 40,000 years before most ions would be depleted from the soil. The highest cation loss was for total PO_4. If 1.2 percent of the total PO_4 were lost each 100 years, it would take 8,300 years for depletion of PO_4 from the soil and rocks. Deficiency conditions would reduce growth before 8,300 years. Microerosion would also expose the roots to freshly weathered soil during that time. Time spans in excess of 500 to 1,000 years are not realistic to management because of the innate change in forest ecosystems. Glaciation, volcanic action, speciation, climatic change, migration, invasion, and other factors will all too soon change the forest that we are trying to manage now.

Table 6.--*Total and available elemental content of a wide range of Coram soils, averaged to 50 cm depth, and calculated as g/0.5 m*^{3}

Parameter	N	Ca	Cu	Fe	K	Mg	Mn	Na	P	Zn
	Element									
Total µg/g	1,190	5,460	29	30,970	20,388	5,551	1,200	6,962	1,688	274
Total g/0.5 m^3	1,142	5,240	28	29,731	19,573	5,329	1,152	6,684	1,621	263
Available g/0.5 m^3	--	857	2.8	30	171	89	44	15	1,144	0.9

Table 7.--*Percentage of total elements removed from a 1 m*^{2} *surface area in logs by a single harvest (clearcut, selection cut, or shelterwood) on the basis of g/0.5 m*^{3} *feeder root zone, relative to total root zone*

Silvicultural practice	Treatment[1]	Ca	Cu	Fe	K	Mg	Mn	N	Na	PO_4	Zn	Percent total cations removed
		Elemental content										
Shelterwood 1	2	1.2	1.2	0.004	0.11	0.17	0.33	2.6	0.01	0.76	0.19	0.17
	4	.4	.5	.002	.04	.14	.10	1.2	.004	.43	.25	.07
	1	.9	1.0	.006	.05	.09	.17	2.4	.02	.25	.19	.12
	3	.6	.7	.003	.05	.07	.13	1.7	.006	.59	.12	.08
Group selection 1	2	1.1	1.1	.001	.12	.15	.23	2.7	.01	1.20	.20	.16
	4	.6	.8	.002	.07	.14	.16	2.1	.007	.63	.10	.09
	1	.5	.6	.002	.05	.06	.11	1.6	.006	.53	.09	.08
	3	.9	.9	.003	.08	.10	.18	2.2	.008	.67	.12	.12
Clearcut 1	2	.4	.5	.001	.04	.12	.10	4.5	.004	.21	.06	.06
	4	1.3	2.0	.004	.09	.23	.42	5.1	.02	.57	.26	.18
	1	.4	.4	.001	.03	.04	.08	4.2	.004	.43	.08	.05
	3	.3	.3	.001	.03	.03	.08	1.4	.004	.36	.05	.05
Shelterwood 2	2	.2	.3	.001	.02	.02	.05	1.2	.002	.26	.05	.03
	4	.4	.4	.001	.03	.03	.08	1.3	.003	.38	.06	.05
	1	.4	.4	.001	.03	.04	.08	4.2	.004	.43	.08	.05
	3	.3	.3	.001	.03	.03	.08	1.4	.004	.36	.05	.05
Group selection 2	2	1.2	1.2	.003	.09	.12	.26	3.0	.01	.87	.20	.16
	4	.8	.8	.002	.07	.08	.16	2.2	.007	.71	.11	.11
	1	1.7	2.9	.005	.11	.13	.25	4.5	.02	.95	.18	.21
	3	.7	.7	.002	.07	.08	.04	2.0	.006	.59	.09	.10
Clearcut 2	2	.9	.9	.002	.09	.09	.14	2.3	.008	.50	.12	.12
	4	.6	.7	.002	.07	.07	.16	1.9	.007	.52	.10	.09
	1	1.1	.9	.003	.09	.09	.22	2.6	.009	.74	.14	.15
	3	.6	1.4	.002	.06	.05	.13	1.6	.005	.42	.07	.08

[1]Treatments described under Methods, least severe to most severe = 2, 4, 1, 3.

When harvest losses are examined on the basis of the percentage of the *available* soil cations removed, larger percentages of ions were taken from the site, representing from 1.9 to 13.9 percent of all the available cations in the root zone at one point in time (table 8). Again, each site varied according to stocking and treatment. The largest percentage losses were for zinc (14.8-91.7 percent of immediately available Zn).

Table 8.--*Representative percentage of available soil elements removed by clearcutting, selective cutting, and shelterwood cutting*

Block	Treatment[1]	Ca	Cu	Fe	K	Mg	Mn	Na	P	Zn	Percent available cations removed
		Element									
Shelterwood 1	2	8.6	13.5	4.7	14.1	11.6	9.9	5.7	1.25	62.7	9.5
	4	3.1	5.7	1.9	5.7	9.7	2.9	2.3	.71	80.1	4.0
	1	6.3	11.5	6.6	7.0	6.5	5.1	8.3	.41	62.6	6.4
	3	4.3	7.9	3.4	6.9	4.6	3.9	3.1	.96	40.3	4.6
Group selection 1	2	7.8	12.8	1.4	16.1	10.5	6.9	5.3	1.98	64.7	9.0
	4	3.9	9.2	2.4	9.3	5.9	4.9	3.8	1.03	33.6	4.9
	1	3.9	6.9	2.0	6.8	4.4	3.4	3.0	.88	29.6	4.3
	3	6.1	10.5	3.0	11.0	6.9	5.6	4.3	1.10	39.6	6.8
Clearcut 1	2	2.7	5.3	1.2	5.2	3.2	2.9	2.1	.34	19.1	3.0
	4	9.1	23.5	4.7	10.5	15.8	12.8	7.9	.94	84.3	10.1
	1	12.2	17.3	3.9	27.4	11.2	9.2	6.8	2.01	91.7	13.9
	3	5.8	13.9	2.8	9.8	8.8	7.5	5.5	.58	48.2	6.6
Shelterwood 2	2	1.7	2.9	1.1	2.6	1.6	1.6	1.2	.43	15.3	1.9
	4	2.5	4.1	1.5	3.9	2.4	2.4	1.7	.63	20.7	2.8
	1	2.6	4.5	1.6	4.1	2.5	2.6	1.9	.71	24.7	2.9
	3	2.3	3.6	1.7	3.7	2.3	2.5	1.9	.59	14.8	2.6
Group selection 2	2	8.3	14.2	4.0	11.4	8.2	7.9	5.6	1.43	65.4	8.9
	4	5.4	8.9	2.5	8.2	5.6	4.9	3.8	1.16	35.9	5.9
	1	11.7	34.2	5.9	13.4	9.3	7.7	9.2	1.57	59.0	11.8
	3	5.2	8.0	2.3	7.8	5.3	1.1	3.3	.96	29.8	5.5
Clearcut 2	2	6.3	9.6	2.6	10.1	6.1	4.4	3.9	.82	38.4	6.9
	4	4.6	8.1	2.4	8.1	4.6	4.9	3.4	.86	31.9	5.2
	1	8.0	11.2	3.1	10.8	6.3	6.5	4.6	1.21	44.4	8.3
	3	4.3	16.5	1.8	6.6	3.8	3.9	2.8	.68	23.2	4.6

[1]Treatments described under Methods.

Only in the case of Zn is there a possible problem with future zinc deficiency because weathering might not be able to replace the needed Zn fast enough to accommodate new growth. This deficiency will probably not occur because burning released added zinc on some treatments, and it will be 20 years or more before the young regeneration is large enough to make severe demands on the soil for zinc. Available nutrients were not actually removed at one time from the soil through harvest, but gradually over a long time (70+ years). Zinc removal to close to 100 percent does not mean that after harvest there was almost no available Zn left in the soil, but the amount of Zn removed in harvest is about what was available in the entire root zone at one point in time. The roots are never able to extract all of the available zinc present in any soil at one time. Some zinc is always present in excess of what is actually being used by roots.

Most other elements showed low percentage losses relative to the available soil cations, normally under 10-15 percent. Calcium losses ranged from 2.3 to 12.2 percent of available Ca, and magnesium from 1.6 to 15.8 percent. Potassium losses were 2.6 to 27.4 percent of available K. Phosphate losses were low (0.3-2.0 percent of available PO_4). Shelterwood showed markedly lower percentage losses of cations when compared to all other blocks. The reason for this is unknown. These data indicate that the system has lost low percentages of the available soil cation and anion pool, and that these ions will not be available after harvest to be recycled through decomposition. The replicate harvest plots were from soils that were somewhat chemically different.

Realistically, the levels of elements taken from the logged sites should be corrected for the elemental input from precipitation (table 9). When corrections are made for precipitation additions as me/m^2 (table 10) the importance of harvest losses is further reduced. This is particularly true if we assume a 70-100 year rotation, and multiply the average additions by 100. Over 100 years, approximately 37 g/m^2 of Ca, 1.3 g of Cu, 5.7 g of Fe, 45 g of K, 31 g of Mg, 2 g of Mn, 120 g of NO_3, 300 g of Na, 15 g of PO_4, and 3 g of Zn, or about 425 g of cations and 140 g of anions would be added to each meter square of the ecosystem. These data apply to only this area where there is enrichment of the atmosphere from an industrial stack (table 9). The harvest losses must be balanced against other liquid and solid elemental losses (smoke, dust, runoff) over the 100 years. At this time, we cannot make this type of prediction, but ultimately this should be possible. This area does not have a permanent stream so that elemental losses to running water could not be measured. Where logging triggers erosion, nutrient losses would be far greater than reported here where erosion was nonexistent.

Harvest data corrected for elemental additions from rainwater show a net gain over 100 years in copper, iron, potassium, magnesium, sodium, nitrogen, phosphate, and zinc (table 9). This means that for most elements studied and for a 100-year rotation, precipitation would restore all but the calcium and manganese removed by harvest in wood and bark. In most cases this holds for a 70-year rotation as well. Calcium and manganese harvest losses would, by calculation, be replaced in 100 years of precipitation for SW2, which had the lowest nutrient losses in the wood and bark harvested. This ecosystem shows high sodium replacement, which may be related to stack emissions from a nearby aluminum plant 11 miles (17.7 km) southwest at Columbia Falls. Clearcutting produced the greatest nitrogen losses, but these would be more than adequately replaced by precipitation and fixation. These results assume no drastic changes in precipitation amounts over 100 years (for calculation purposes).

Only a few studies have dealt with nutrient removal through harvest. Weaver and Forcella (in press) reported that nutrient losses from whole tree harvest reduced ecosystem nitrogen by about 3x, phosphorus by 6x, potassium by 4x, and calcium by 3x compared to conventional log removal.

Long and Turner (1975) have described the aboveground biomass of understory and overstory Douglas-fir stands by age class. Odegard (1974) discussed nutrient and biomass relationships following clearcutting of lodgepole pine forests. Ovington and others (1973) described the biomass and nutrient capital of old-growth Douglas-fir stands. Few studies have included information taken directly from harvest. Carlisle (1967) showed that for oak forests nutrient input from precipitation in 12 years replaced harvest losses for 60- or 120-year rotations.

Weetman and Webber (1971) concluded that full-tree logging would not damage the soil for the next crop of spruce, with the possible exception of calcium deficiencies. They felt that sites of marginal fertility should not be subjected to full-tree logging unless fertilizer is applied to the soil. This view was also expressed by Tamm (1969). Other data showed large inputs of nutrients from dust and precipitation. Wilde and others (1972) showed that red pine can grow on soils which by chemical analysis show low fertility. These and other data point to a growing belief that forest trees can extract more nutrients from soil than are reflected in chemical analysis (Bowen 1972).

Table 9.--*Average annual and 100-year expanded additions of ions to the forest ecosystem from bulk precipitation*

Ion	Time span: Average annual	Time span: 100 years	Ion	Time span: Average annual	Time span: 100 years
	Grams/square meter			*Grams/square meter*	
Ca	0.37	37.0	NO_3	1.20	120.0
Cu	.013	1.3	Na	3.0	300.0
Fe	.057	5.7	PO_4	.149	14.9
F	.055	5.5	Zn	.031	3.1
K	.453	45.3	Cations	--	425.0
Mg	.306	30.6	Anions	--	140.0
Mn	.019	1.9			

Table 10.--*Levels of elements removed in wood and bark from the Coram Experimental Forest, corrected for estimated 100-year elemental additions from bulk precipitation*

Block[1]	Treatment[2]	Ca	Cu	Fe	K	Mg	Mn	N	Na	P	Zn
		g/m²/100 years									
Shelterwood 1	2	26	+0.9	+4.5	+25	+22	1.9	+91.3	+299	+2.6	+2.6
	4	+14	+1.2	+5.2	+37	+23	+ .8	+106.8	+300	+7.9	+2.5
	1	9	+1.0	+4.0	+35	+26	.02	+93.8	+299	+10.8	+2.6
	3	+6	+1.1	+4.8	+35	+27	+ .4	+101.2	+300	+5.4	+2.8
Clearcut 1	2	+18	+1.2	+5.4	+38	+28	+ .8	+70.2	+300	+11.5	+2.9
	4	30	+ .7	+4.5	+28	+18	2.9	+62.9	+299	+5.7	+2.4
	1	53	+ .9	+4.7	+5	+22	1.6	+32.9	+299	4.9	+2.4
	3	5	+ .9	+4.9	+31	+24	.9	+72.9	+299	+9.2	+2.7
Shelterwood 2	2	+24	+1.2	+5.4	+41	+29	+1.3	+107.2	+300	+10.6	+3.0
	4	+18	+ .3	+5.3	+39	+29	+1.0	+105.8	+300	+8.7	+2.9
	1	+18	+1.2	+5.3	+39	+29	+ .9	+73.3	+300	+7.9	+2.9
	3	+20	+ .4	+5.3	+39	+29	+ .9	+104.2	+300	+9.1	+3.0
Clearcut 2	2	10	+1.1	+5.0	+29	+29	.2	+94.4	+299	+6.8	+2.8
	4	+3	+1.1	+5.1	+32	+29	+ .01	+98.9	+300	+6.4	+2.8
	1	22	+1.0	+4.9	+28	+28	.6	+91.0	+299	+3.0	+2.7
	3	+5	+ .9	+5.2	+34	+29	+ .4	+102.2	+300	+8.2	+2.9

[1]No precipitation data are available for the group selection plots.
[2]Treatments described under Methods.

+ = additions of elements above levels removed on a 100-year rotation. Other figures represent amount by which precipitation fails to replace harvest losses.

Cole and others (1967) discuss the problem of determining accurately the quantity of nutrients released by geochemical weathering.

The nitrogen content of spruce slash was reported as 167 to 387 kg/ha. This constitutes a major source of the potentially mineralized organic N (Weetman and Webber 1971). This same study concluded that adequate nitrogen would be left in the litter and humus layer to support the next forest (initially), even with tree-length logging. Gessel and Cole (1965) found that the removal of vegetation resulted in a 6 percent loss of K below the root zone.

CONCLUSIONS

On the relatively fertile soils at Coram, none of the harvest intensities used (clearcut, shelterwood, or group selection) with varying degrees of site preparation removed nutrients in amounts that should affect growth for thousands of years. Nutrient losses did vary by treatment, but not in amounts significant to management. One unknown in evaluating the impact of land use on nutrient losses is our inability to determine accurately how fast rock weathers with depth. The weathering rate is the key interest rate at which nutrients are made soluble and available to plants. Leaching losses represent the permanent expenditure of biologically essential nutrients from the system. The amounts of nutrients removed in the harvest of logs, even with clearcutting, will normally be replaced by bulk precipitation in from 70 to 100 years. This should hold true when the harvested species are alpine fir, Douglas-fir, western larch, western white pine, western redcedar, lodgepole pine, Engelmann spruce, and western hemlock on similar soils. Unfortunately, we cannot put long-term dollar values on the nutrients lost.

Skyline logging did not produce serious erosion or soil losses. This is surprising in view of the steep terrain (45 percent) and the fire lines that had to be built. Certainly these results could not be extrapolated to any area of similar topography. The combination of a productive surface soil with abundant organic matter and a tremendously dense herb and shrub layer prevented erosion. The surface disturbance from this method of logging was minimal, and the vigorous regrowth of vegetation held both nutrients and soil in place.

This vigorous regrowth probably also explains the low levels of solution nutrient loss from the system. The ephemeral stream, Abbott Creek, was essentially unaltered chemically by the extensive logging of the watershed that feeds it. Part of this is the result of the underground transit of this stream, and part results from rapid regrowth of the vegetation preventing excessive nutrient losses from the slopes.

Clearcutting exported more nutrients below the root zone than did any of the other treatments. These nutrient losses were low and only slightly elevated above those of the controls. They were also relatively short-lived. Logging temporarily increased the levels of F, Mg, Mn, NO_3, Na, and Zn in the soil water. These nutrients appear to have come from rapid winter decay of needles under a deep, dense snowpack. Soil water appears to be the best and most dependable indicator of the levels of available nutrients in soil.

Burning increased soil water ion loads for a year, but the burns were of low intensity and the ion additions were all quite low. Data on the nutrient content of the vegetation suggests that the herbs and shrubs were taking up large quantities of the nutrients released from burning. This study demonstrated that skyline logging as practiced on these slopes with this soil did not result in massive solution or erosion nutrient losses. The harvest losses in wood and bark were also relatively low and will be replaced by precipitation if not by weathering during the next rotation.

APPLICATIONS

One important use of these results is to compare other areas to be logged to Coram. Appendix B shows details of the soil characteristics of the area, and Appendix A provides an idea of species diversity. Appendix C shows the range of soil chemistry for the general study area. Areas that vary considerably from this area in terms of soil chemistry, soil physical properties, slope, aspect, or vegetation should be looked at carefully before extrapolating these results. Quite different results could be expected on steeper slopes, for example. An erosive soil, such as some silt loams, fine sands, or some loams or silts would produce potentially higher nutrient losses than occurred at Coram. Clay soils may cause accelerated surface losses. Also, older soils more highly weathered may lose fertility faster if exposed to this type of nutrient loss, even at low levels. Fertile soils will probably suffer less than very poor soils. Talus slopes with low total soil depth, little weathered, and with extremely low levels of available nutrients may not be able to withstand this type of logging treatment without irreparable nutrient losses. A different system of removing logs will surely produce different degrees of surface disturbance and more or less nutrient loss as well as differences in erosion. Hotter fires would create a greater chance of nutrient losses and could alter the conclusions reached here. Even a south slope with sparse vegetation and different species will respond in an altered manner to logging, and would be expected to lose more nutrient in years of heavy precipitation. A permanent, aboveground stream will react differently to disturbance on the slope. Infiltration is also a big factor in nutrient loss. Soils that characteristically freeze deeply in winter or that have heavy clay surfaces may well produce overland nutrient losses not encountered at Coram. Even the Coram slopes may alter their nutrient losses in a year of exceptionally heavy precipitation, or very light or heavy snowpack.

Different land use history may influence the response of an area to logging. Heavily compacted soils, or flat ground will release nutrients differently than occurred at Coram. Also important is stoniness or rockiness. The heavy stone content of Coram soils aided infiltration and percolation of water and made this soil more able to store the modest amounts of nutrients released from logging and burning. Certainly a change in vegetation type would alter the ability of a site to absorb and retain nutrients. Vegetation which sprouts and regrows rapidly should be best suited to logging disturbance, but not necessarily to regeneration of trees. The intensity and method of site preparation will alter a site's ability to retain nutrients. High water tables and moist sites will lose nutrients readily. Logging must be evaluated in terms of the holocoenotic environment, the whole that is influenced in many ways by all of its parts.

Every area to be logged is a bit different. The greater the difference from the Coram study site, the greater the chances of more or less nutrient losses. Harvest will probably not remove significant levels of nutrients from any but the poorest very old or very young soils. Solution losses are highly dependent on the depth of soil, amount of precipitation, amounts of carbonates and bicarbonates in the soil solution, soil texture, and clay and organic content, and the cation and anion exchange capacities.

We are not yet ready to write prediction equations for any forest in terms of nutrient retention for any treatment, but we do have a "feel" for the types of areas that will suffer most from logging or fire. Current logging and burning studies on predominantly clay soils will add to this knowledge. We might not always be able to say how much different conditions need to be from those at Coram to be significant.

More work needs to be done on nutrient removal associated with heavy utilization. We need to answer the question, "How much fiber can be removed from a site before the ability of the soil to grow the next rotation is impaired?" We are working on this. Because the Coram study showed no serious nutrient losses, we cannot assume that any forest or soil will respond the same way. We are, however, in a good position to estimate the magnitude of losses on other sites.

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APPENDIX A

Plant Species Found on Coram Forest

Table 11.--*Habitat type and phase codes, utilization study, Coram Experimental Forest*[1]

1974 map	1977 abbreviation	Scientific name
D/P-P	PSME/PHMA h.t.-PHMA phase	*Pseudotsuga menziesii/Physocarpus malvaceus* h.t., *Physocarpus malvaceus* phase
H/C-A	TSHE/CLUN h.t.-ARNU phase	*Tsuga heterophylla/Clintonia uniflora* h.t., *Aralia nudicaulis* phase
A/O	ABLA/OPHO h.t.	*Abies lasiocarpa/Oplopanax horridum* h.t.
A/C-C	ABLA/CLUN h.t.-CLUN phase[2]	*Abies lasiocarpa/Clintonia uniflora* h.t., *Clintonia uniflora* phase
A/C-A	ABLA/CLUN h.t.-ARNU phase	*Abies lasiocarpa/Clintonia uniflora* h.t., *Aralia nudicaulis* phase
A/C-X-P	ABLA/CLUN h.t.-XETE phase[2]	*Abies lasiocarpa/Clintonia uniflora* h.t., *Xerophyllum tenax* phase
A/C-M	ABLA/CLUN h.t.-MEFE phase	*Abies lasiocarpa/Clintonia uniflora* h.t., *Menziesia ferruginea* phase

[1]Jack Schmidt and Robert Pfister, Intermountain Forest and Range Experiment Station, Forestry Sciences Laboratory, Missoula, Montana.

[2]*Physocarpus malvaceus* well represented in undergrowth community.

Plant Species Found on Coram Forest*

Abies lasiocarpa
Acer glabrum
Actea rubra
Adenocaulon bicolor
Alnus sinuata
Amelanchier alnifolia
Antennaria spp.
Aralia nudicaulis
Arnica cordifolia
Arnica latifolia
Aster conspicuus
Aster laevis
Athyrium filix-femina
Berberis repens
Bromus vulgaris
Calamagrostis canadensis
Calamagrostis rubescens
Carex concinoides
Carex geyeri
Carex rossii
Chimaphila umbellata
Cirsium vulgare
Clematis columbiana
Clintonia uniflora
Cornus canadensis
Disporum hookerii
Disporum trachycarpum
Dracocephalum parviflorum
Elymus glacus
Epilobium angustifolium
Epilobium watsonii
Equisetum spp.
Festuca occidentalis
Fragaria vesca
Galium triflorum
Gentiana amarella
Geranium bicknellii
Goodyera oblongifolia
Gymnocarpium dryopteris
Hieracium albiflorum
Larix occidentalis
Linnaea borealis
Lonicera utahensis
Melica subulata
Menziesia ferruginea
Oryzopsis asperifolia
Osmorhiza chilensis
Pachistima myrsinites
Pedicularis bracteosa
Pedicularis contorta
Pedicularis racemosa
Physocarpus malvaceus
Picea engelmannii
Pinus monticola
Pseudotsuga menziesii
Pyrola asarifolia
Pyrola secunda
Ribes lacustre
Ribes viscossissimum
Rosa acicularis
Rosa gymnocarpa
Rubus parviflorus
Salix scouleriana
Sorbus scopulina
Smilacina racemosa
Smilacina stellata
Spirea betulifolia
Symphoricarpos albus
Taxus brevifolia
Tiarella unifoliata
Trillium ovatum
Tsuga heterophylla
Vaccinium membranaceum
Vaccinium myrtillus
Viola adunca
Viola orbiculata
Xerophyllum tenax
Anaphalis margaritacea
Apocynum androsaemifolium
Betula papyrifera
Calochortus nuttallii
Ceanothus sanguineus
Comandra umbellata
Cornus stolonifera
Habenaria dilitata
Polystichum munitum
Pteridium aquilinum
Senecio pseudaureus
Senecio triangularis
Shepherdia canadensis
Taraxacum officinale

*U.S. Forest Service list.

APPENDIX B

Soil Characteristics, Coram Forest

Table 12.--*Soil description, Coram Forest, lower slope, adapted from Eron 1977*

Horizon	Depth	Thickness	Color		Field texture analysis	Structure	Consistency (moist)	Roots	Boundary	Reaction
			Dry	Moist						
	- - - - cm	- - - -								
01	7.0-3.0	4.0	--	--	--	--	--	fine few	clear smooth	--
02	3.0-0.0	3.0	--	--	--	--	--	fine common	clear smooth	--
A2	0.0-1.5	1.5	10 yr 6/1	4/2	silt loam	weak fine crumbly	very friable	fine common	clear smooth	--
B2	1.5-35.0	33.5	10 yr 6/3	4/4	silt loam	moderate fine crumbly	very friable	fine many	clear smooth	pH=6.3 %M=52.5 (14.5 cm depth)

Date: August 12, 1976
Soil type: gravelly silt-loam
Soil series: Sherlock (Klages and others 1976)
Soil subgroup: andeptic cryobonalf (Klages and others 1976)
Family: loamy-skeletal, mixed (Klages and others 1976)
Elevation: ~1800 m
Slope: ~5%-10%
Aspect: east
Parent material: glacial till (Klages and others 1976)
Habitat type: *Tsuga heterophylla/Clintonia unifloria* (Pfister and others 1977)

Organic matter upper 5 cm: 11.8%-15.6%
Hydraulic conductivity: 8.2-11.3 cm/h
Water holding capacity: 5 cm, 22%; B_2, 11%
Infiltration rate: 4 in (10.2 cm)/h

Table 13.--*Soil description, Coram Forest, upper slope, adapted from Eron 1977*

Horizon	Depth	Thickness	Color		Field texture analysis	Structure	Consistency (moist)	Roots	Boundary	Reaction
			Dry	Moist						
	- - - - cm	- - - -								
01	3.0-2.0	1.0	--	--	--	--	--	fine few	gradual smooth - clear smooth	--
02	2.0-0.0	2.0	--	--	--	--	--	fine few	gradual smooth - clear smooth	--
A2	0.0-1.0	1.0	10 yr 5/1	10 yr 4/1	silt loam	weak fine crumbly	very friable - friable	fine few	gradual smooth - clear smooth	--
B2	1.0-40.0	39.0+	10 yr 7/1	10 yr 4/3	silt loam	weak - moderate fine crumbly	firm	fine - medium common - many	gradual smooth - clear smooth	pH=6.1 %M=62.5 (at 14.5 cm depth)

Date: August 13, 1976
Soil type: gravelly silt-loam
Soil series: Felan (Klages and others 1976)
Soil subgroup: andic cryochrept (Klages and others 1976)
Family: loamy-skeletal, mixed (Klages and others 1976)
Elevation: ~1970 m
Slope: ~60%
Aspect: east
Parent material: limestone (Klages and others 1976)
Habitat type: *Abies lasiocarpa/Clintonia uniflora*
(Pfister and others 1977)

Average Cation Exchange Capacity of Coram Soils

Depth (cm)	*Cation exchange (me/100 g)*
0-5	13.10
5-10	9.05
10-15	9.63
15-20	8.78
20-25	9.23
25-30	8.23
30-35	9.08
35-40	9.63
40-45	13.53
45-50	6.25
Average	9.65

Table 14.--*Characteristics of Coram soils: particle density, particle size, organic content*

PARTICLE CHARACTERISTICS

Particle weight[1]		Particle size	
>1 mm	<1 mm	>1 mm	<1 mm
g/cm^3		*Percent*	
0.830	0.451	64.55	35.45

ORGANIC CONTENT

Block	Soil depth		
	0-5 cm	20-25 cm	50-55 cm
11	14.59	3.57	1.94
	7.39	4.26	2.76
	12.74	5.06	1.96
	12.64	5.92	2.20
21	8.64	6.00	4.56
	9.41	7.33	4.93
	7.76	10.86	13.43
	17.73	5.16	3.23
13	9.15	3.62	2.60
	11.29	5.79	2.62
	5.33	3.87	3.80
	10.71	5.24	5.63
23	17.53	5.24	2.28
	10.98	7.91	2.34
	13.86	6.53	3.99
	12.12	7.45	3.09

[1]Average particle density = 2.56 g/cm^3.

APPENDIX C

Average Elemental Content of Coram Forest Soil Samples

Table 15.--*Average elemental content of 0.002 N H_2SO_4 soil extract from Coram, as μg/g, by depth and plot, all months combined (pretreatment)*

Plot	Sub	H^+	Element									
			Ca	Cu	Fe	K	Mg	Mn	Na	N	PO_4	Zn
		Molar										
			May and October 1973									
0-5 cm												
11	1	0.74^{-6}	1089	2	24	291	113	83	13	1766	101	3
	2	0.22^{-5}	914	2	23	282	124	166	18	1920	77	2
	3	0.66^{-6}	1283	3	33	375	144	93	19	2608	107	2
	4	0.12^{-5}	1166	2	25	329	114	100	23	2203	105	2
21	1	0.20^{-5}	991	3	29	234	102	96	12	1644	50	3
	2	0.12^{-5}	1124	3	26	251	127	103	17	1780	74	2
	3	0.12^{-5}	1160	2	25	285	147	81	12	1953	71	2
	4	0.64^{-6}	1257	2	20	319	153	89	12	2843	95	2
13	1	0.78^{-6}	1277	2	20	240	106	82	13	2280	84	2
	2	0.25^{-5}	1072	3	27	193	133	93	15	2313	94	2
	3	0.14^{-5}	1290	3	33	288	96	76	11	1825	74	2
	4	0.36^{-5}	1224	3	42	254	104	89	14	2016	86	2
23	1	0.39^{-5}	1082	3	20	257	103	141	14	3158	70	2
	2	0.17^{-5}	1098	2	17	255	91	132	14	2229	46	1
	3	0.53^{-5}	1035	2	18	208	105	194	16	2935	41	2
	4	0.34^{-5}	1058	2	27	240	117	133	9	2120	84	2
14	5	0.96^{-6}	1203	3	24	292	124	96	12	2471	56	1
24	5	0.29^{-5}	1281	2	19	228	127	115	14	2046	82	1
20-25 cm												
11	1	0.99^{-6}	725	2	44	160	69	23	22	648	53	1
	2	0.19^{-5}	698	3	36	144	67	38	25	702	43	2
	3	0.11^{-5}	850	3	45	247	87	33	29	1023	29	1
	4	0.98^{-6}	857	3	30	196	78	27	31	827	25	1
21	1	0.18^{-5}	750	3	29	150	78	33	14	832	21	1
	2	0.14^{-5}	870	3	23	189	92	38	22	1285	21	1
	3	0.15^{-5}	931	3	31	172	126	21	14	973	30	1
	4	0.12^{-5}	775	3	27	180	105	26	15	962	25	1
13	1	0.10^{-5}	876	3	30	135	74	18	15	644	38	1
	2	0.26^{-5}	865	3	32	119	118	39	15	1140	43	1
	3	0.96^{-6}	1022	3	46	139	77	15	15	766	28	1
	4	0.26^{-5}	879	3	49	146	76	13	18	706	29	1
23	1	0.26^{-5}	827	3	20	157	63	51	19	1077	24	1
	2	0.20^{-5}	594	3	20	131	46	42	20	1154	5	1
	3	0.22^{-5}	757	2	25	131	62	44	21	1289	22	1
	4	0.44^{-6}	793	3	32	149	74	40	14	1012	45	1
14	5	0.17^{-5}	1041	3	46	185	103	18	14	1044	23	1
24	5	0.29^{-5}	853	3	26	149	92	33	17	932	34	1

(Cont.)

Table 15.--*Average elemental content of 0.002 N H_2SO_4 soil extract from Coram, as μg/g, by depth and plot, all months combined (pretreatment)--Continued*

Plot	Sub	H^+	Element									
			Ca	Cu	Fe	K	Mg	Mn	Na	N	PO_4	Zn
		Molar										
			May and October 1973 (continued)									
50-55 cm												
11	1	0.71^{-6}	588	3	27	87	63	14	15	310	29	1
	2	0.14^{-5}	640	3	28	105	79	17	19	337	20	1
	3	0.96^{-6}	591	3	38	130	81	16	19	615	23	1
	4	0.10^{-5}	596	3	22	102	77	17	22	402	19	1
21	1	0.24^{-5}	694	3	25	147	84	19	16	485	20	1
	2	0.29^{-5}	682	3	22	102	75	15	12	556	18	1
	3	0.14^{-5}	778	3	39	120	133	14	11	719	22	1
	4	0.19^{-5}	656	3	26	130	78	15	14	486	15	1
13	1	0.73^{-6}	910	3	42	115	87	18	13	582	15	1
	2	0.10^{-5}	938	3	29	85	99	14	14	445	18	1
	3	0.59^{-6}	1372	3	54	102	82	10	13	648	12	1
	4	0.15^{-5}	976	3	67	107	68	8	13	631	21	1
23	1	0.13^{-5}	657	3	17	127	63	22	13	535	14	1
	2	0.37^{-5}	430	3	19	76	60	19	11	419	9	1
	3	0.31^{-5}	627	3	20	93	67	30	17	587	13	1
	4	0.24^{-5}	673	3	21	100	63	45	14	581	27	1
14	5	0.10^{-5}	1418	3	58	149	99	12	14	796	16	0
24	5	0.17^{-5}	806	3	23	86	105	21	15	593	16	0
			May 1974									
0-5 cm												
11	1	0.63^{-6}	743	2	21	219	76	41	10	976	85	2
	2	0.16^{-5}	727	2	22	198	77	85	16	3150	54	2
	3	0.98^{-6}	1005	2	18	350	124	55	14	2081	70	1
	4	0.10^{-5}	995	2	15	282	96	42	16	1422	57	1
21	1	0.15^{-5}	1185	4	64	308	157	148	10	1554	174	6
	2	0.12^{-5}	1418	4	51	274	180	151	10	2303	168	4
	3	0.84^{-6}	1564	4	38	249	167	87	10	1982	82	2
	4	0.89^{-6}	1290	3	21	233	186	75	10	1885	68	2
13	1	0.38^{-6}	1105	2	27	431	160	63	16	1105	70	1
	2	0.46^{-5}	658	2	43	162	80	56	18	1051	61	2
	3	0.95^{-6}	1187	2	41	576	90	42	19	1439	63	1
	4	0.37^{-5}	1042	2	35	209	87	85	18	1709	43	2
23	1	0.69^{-6}	1198	3	23	257	133	127	13	2268	74	1
	2	0.67^{-6}	1204	3	27	241	96	79	15	2308	47	1
	3	0.27^{-5}	957	3	34	206	83	158	18	2791	39	2
	4	0.88^{-6}	1047	3	33	210	121	65	9	1441	71	2
14	5	0.15^{-6}	1185	2	44	279	109	72	11	1562	63	1
24	5	0.10^{-5}	957	2	40	215	109	62	15	1514	40	1

(Cont.)

Table 15.--*Average elemental content of 0.002 N H_2SO_4 soil extract from Coram, as µg/g, by depth and plot, all months combined (pretreatment)--Continued*

Plot	Sub	H^+	Element									
			Ca	Cu	Fe	K	Mg	Mn	Na	N	PO_4	Zn
		Molar										
						May 1974 (continued)						
20-25 cm												
11	1	0.72^{-6}	746	2	36	155	79	10	15	598	41	1
	2	0.13^{-5}	647	2	24	129	65	19	21	927	18	1
	3	0.96^{-6}	809	2	15	190	90	10	17	706	16	1
	4	0.61^{-6}	856	2	15	237	90	8	20	823	14	1
21	1	0.95^{-6}	801	4	60	196	109	36	14	869	92	1
	2	0.11^{-5}	743	4	53	159	87	31	20	1100	105	1
	3	0.12^{-5}	1128	4	66	175	180	22	11	1014	40	1
	4	0.83^{-6}	673	4	50	201	123	21	13	882	46	1
13	1	0.97^{-6}	878	2	28	259	136	26	26	1460	26	1
	2	0.24^{-5}	722	2	34	119	92	27	19	710	32	1
	3	0.96^{-6}	1053	1	30	250	72	10	21	710	13	1
	4	0.18^{-5}	923	2	27	141	78	9	22	749	8	1
23	1	0.98^{-6}	707	3	31	162	60	27	17	904	26	0
	2	0.54^{-6}	593	3	27	136	47	18	17	925	7	0
	3	0.79^{-6}	821	3	32	95	61	18	21	1525	25	0
	4	0.62^{-6}	774	3	37	179	71	20	11	687	47	0
14	5	0.24^{-6}	1029	2	78	209	82	13	15	773	21	1
24	5	0.63^{-6}	716	2	31	165	98	33	19	897	18	1
50-55 cm												
11	1	0.70^{-6}	508	2	19	72	64	6	15	326	14	0
	2	0.14^{-5}	509	2	19	90	57	9	15	402	17	0
	3	0.63^{-6}	540	3	19	100	86	10	13	476	14	1
	4	0.70^{-6}	505	2	14	82	64	8	14	323	7	1
21	1	0.59^{-6}	530	5	36	86	88	13	11	426	33	1
	2	0.14^{-5}	483	4	26	85	61	14	11	425	26	1
	3	0.10^{-5}	911	4	97	136	221	13	11	960	23	1
	4	0.10^{-5}	482	4	25	101	74	12	10	459	19	1
13	1	0.89^{-6}	889	2	25	114	79	10	17	491	11	1
	2	0.11^{-5}	730	2	28	90	111	13	16	455	7	1
	3	0.80^{-6}	1577	1	40	106	76	8	20	799	7	0
	4	0.49^{-6}	1419	1	32	193	112	7	19	551	4	0
23	1	0.92^{-6}	572	3	27	98	63	13	13	442	19	0
	2	0.61^{-6}	451	3	19	73	68	7	10	292	11	0
	3	0.89^{-6}	642	3	24	84	88	16	17	540	19	0
	4	0.55^{-6}	619	3	24	93	61	23	11	389	35	0
14	5	0.29^{-6}	1407	2	85	169	92	7	15	769	13	1
24	5	0.52^{-6}	764	2	30	95	91	32	20	725	14	1

(Cont.)

Table 15.--*Average elemental content of 0.002 N H_2SO_4 soil extract from Coram, as µg/g, by depth and plot, all months combined (pretreatment)--Continued*

Plot	Sub	H^+	Element									
			Ca	Cu	Fe	K	Mg	Mn	Na	N	PO_4	Zn
		Molar										
			All depths, plots, and months combined									
Average		0.10^{-5}	895	3	36	184	98	38	15	1078	40	1
S.D.		0.14^{-5}	426	1	35	177	68	47	6	1035	54	1
Percent nutrient balance		--	70.43	0.21	2.85	14.50	7.70	3.00	1.21	--	--	0.08

Total cations = 1270
Total anions = 593

Stark, Nellie M.
1979. Nutrient losses from timber harvesting in a larch/ Douglas-fir forest. USDA For. Serv. Res. Pap. INT-231, 41 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Nutrient levels as a result of experimental clearcutting, shelterwood cutting, and group selection cutting--each with three levels of harvesting intensity--were studied in a larch-fir forest in northwest Montana, experimentally logged with a skyline system. None of the treatments altered nutrient levels in an intermittent stream, nor were excessive amounts of nutrients lost in soil below the root zone. Under conditions on this site, skyline logging did not result in surface erosion or nutrient losses that would affect forest management.

KEYWORDS: Harvest, nutrient cycling, nutrient loss, water quality.

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