



Soil Disturbance, Vegetative Cover and Regeneration on Clearcuts

**IN THE NELSON FOREST DISTRICT,
BRITISH COLUMBIA**

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ABSTRACT

Concern over the amount of soil disturbance associated with clearcut logging on steep slopes in the Nelson Forest District led, in 1973, to the formulation of general Forest Service regulations governing ground skidding operations. This was followed by the formation of the multi-agency Steep Slope Committee, which had as one of its objectives a description of the extent and severity of soil disturbance over a range of sites and logging methods. To this end, data were collected in the summers of 1974 and 1975 from 9,361 mil-acre plot and point samples along 78 transects distributed widely throughout the Nelson Forest District to describe soil and vegetative conditions on steep-slope clearcuts. The most soil disturbance was caused by ground skidding operations on bare ground (average 45% of the clearcut area) and the least by skyline logging. Ground skidding on snow and high-lead cable systems reduced soil disturbance by about one-half compared with summer ground skidding. Soil disturbance on ground between haul roads and skidroads was much less extensive than that related to roads but was increased by two to four times by broadcast slash burning. Vegetative cover increased steadily with time following logging on both burned and unburned surfaces between roads, but was higher after 11 years on the latter as a result of a greater initial cover of residual vegetation. Excluding planting, areas between roads in unburned clearcuts and road surfaces in both burned and unburned clearcuts were satisfactorily restocked with new and advance regeneration after about 9 years. Surfaces between roads in burned clearcuts were not satisfactorily restocked up to 10.5 years, the average age of the oldest burned clearcuts examined. Differences in vegetative cover and stocking of regeneration were noted among biogeoclimatic zones. Examples of soil erosion were recorded and described. Recommendations for further surveys and research are made.

RÉSUMÉ

Les soucis à propos de la détérioration du sol causée par les exploitations par coupe rase sur les flancs escarpés de collines du district forestier de Nelson ont abouti, en 1973, à la formulation de règlements généraux du Forest Service, pour régir les opérations de débusquage terrestre.

Par la suite, on a formé le "Steep Slope Committee", un comité regroupant plusieurs organismes, qui avait comme objectif de décrire l'étendue et la gravité des détériorations du sol sur une gamme de stations et par suite de méthodes diverses d'exploitation forestière. Dans ce but, on a recueilli des données au cours des étés de 1974 et 1975, dans 9,361 placettes d'une milli-acre et placettes circulaires à rayon variable le long de 78 transects largement distribués à travers le district forestier Nelson, afin de décrire les conditions du sol et de la végétation dans les aires de coupes rases sur pentes escarpées. La plus sévère détérioration fut causée par les opérations de débusquage sur le sol nu (moyenne de 45% de superficie coupée à blanc) et la moindre fut causée par le débardage par câble-grue. Le débusquage terrestre sur la neige et les systèmes de débardage aérien ont diminué la détérioration du sol de moitié environ, par rapport au débusquage terrestre d'été. Le sol détérioré sur le terrain situé entre les chemins de débardage et de débusquage fut beaucoup moindre que celui dans les chemins mais fut doublé ou triplé par un brûlage extensif des rémanents. Le couvert végétal augmenta continuellement avec le temps, après une coupe (que les surfaces fussent ensuite brûlées ou non), entre les chemins, mais il était plus haut après 11 ans dans le second cas à cause d'un couvert végétal initial plus grand, provenant des résidus de végétation. Si on exclut le plantage, les secteurs entre les chemins dans les coupes à blanc non brûlées et les surfaces routières des coupes rases suivies ou non de brûlages furent repeuplés de façon satisfaisante avec un matériel de reproduction nouveau ou pré-établi au bout d'environ 9 ans. Les surfaces entre les chemins dans les forêts coupées à blanc puis brûlées ne furent pas repeuplées de manière satisfaisante avant jusqu'à 10.5 ans, âge moyen du secteur rasé puis brûlé le plus vieux qu'on ait inspecté. On a noté des différences du couvert végétal et des stocks de reproduction parmi les zones biogéoclimatiques. Des exemples d'érosion du sol furent notés et décrits. Les auteurs formulent des recommandations à propos de relevés et recherches subséquents.

ABBREVIATIONS USED IN TEXT

Logging Methods

- GS - Ground skidding
- HL - High-lead
- GY - Grapple yarding
- JY - Jammer yarding
- SL - Skyline
- S - Summer, as in SHL (Summer high-lead)
- W - Winter, as in WHL (Winter high-lead)
- (u) - Unburned, as in WGS (u) (Winter ground skidding (unburned))
- (b) - Burned, as in SGS(b) (Summer ground skidding (burned))

Biogeoclimatic Zones

- IDF - Interior Douglas-fir
- IWH - Interior Western Hemlock
- ESSF - Engelmann Spruce - Subalpine Fir

SCIENTIFIC NAMES OF TREE SPECIES

- | | |
|--------------------|---|
| Aspen | - <u>Populus tremuloides</u> Michx. |
| Birch | - <u>Betula papyrifera</u> Marsh. |
| Cottonwood | - <u>Populus trichocarpa</u> Torr. & Gray |
| Douglas-fir | - <u>Pseudotsuga menziesii</u> (Mirb.) Franco |
| Engelmann spruce | - <u>Picea engelmannii</u> Parry |
| Lodgepole pine | - <u>Pinus contorta</u> Dougl. |
| Subalpine fir | - <u>Abies lasiocarpa</u> (Hook.) Nutt. |
| Western hemlock | - <u>Tsuga heterophylla</u> (Raf.) Sarg. |
| Western larch | - <u>Larix occidentalis</u> Nutt. |
| Western red cedar | - <u>Thuja plicata</u> Donn |
| Western white pine | - <u>Pinus monticola</u> Dougl. |

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SYNOPSIS OF RESULTS

Scope of Survey

1. The survey was conducted in the West and East Kootenay Regions at elevations ranging from 838 to 1,905 m and on slopes of 30 to 81% (avg 58%). The age of logging varied from 0 to 23 years (avg 5.2 years).
2. Sampling occurred in three biogeoclimatic zones: Interior Douglas-fir (IDF), Interior Western Hemlock (IWH) and Engelmann Spruce-Subalpine Fir (ESSF) and in two transitions (IDF/ESSF and IWH/ESSF).
3. Seventy-eight transects (subdivided into 121 segments) were examined and data were collected from 9,361 point samples and mil-acre plots.
4. On 13 transects established in 1974, an additional 1,628 points were resurveyed in 1975 to determine changes in vegetative cover.
5. Most sampling was conducted in six major logging method/post harvesting treatment combinations:
 - a) summer ground skidding, burned and unburned (SGS(b) and SGS(u))
 - b) winter (on snow) ground skidding, burned and unburned (WGS(b) and WGS(u))
 - c) summer high-lead, burned and unburned (SHL(b) and SHL(u)).

Fewer samples were obtained for:

- a) winter high-lead, unburned (WHL(u))
- b) summer grapple-yarding, unburned (SGY(u))
- c) winter grapple-yarding, unburned (WGY(u))
- d) summer jammer yarding, unburned (SJY(u))
- e) summer skyline, unburned (SSL(u)).

Soil Disturbance - Roads (including skidroads)

1. An average of 39.8% of the area of SGS clearcuts was disturbed (mineral soil exposed) by skidroads and main (haul) roads, almost twice that for WGS clearcuts (21.3%). The least road-related disturbance was produced by SSL, SJY, SHL and WHL operations.

2. Very deep disturbance (gouges or deposits over 25-cm deep) produced by roads amounted to 28.3% of the area of SGS clearcuts, 12.8% of WGS clearcuts and 9.1% of SHL and WHL clearcuts.

3. Skidroads were the major source of road disturbance in GS clearcuts, main roads in HL and JY clearcuts and tail-hold roads in GY clearcuts.

4. Of the disturbance produced by main roads, 85.1% was categorized as very deep. Of that produced by skidroads and tail-hold roads, 66.2 and 61.7%, respectively was categorized as very deep.

5. Points on winter skidroads were classified less frequently as very deeply disturbed (54.7%) than on summer skidroads (68.5%).

6. Within the range of slopes studied, there was no correlation between degree of slope and amount of disturbance caused by summer skidroads. In contrast, winter skidroads produced more than twice as much disturbance on slopes over 60% as on slopes less than 60%.

7. There was a tendency for skidroads to be steepest on the gentlest slopes examined.

Soil Disturbance - Between Roads

1. Disturbance (gouges and deposits) between roads constituted only 3.9% of the area of GS(u) clearcuts and 8.4% of HL(u) clearcuts. Disturbance between roads on burned clearcuts amounted to 19.8% of the area for SGS, 33.1% for WGS and 56.2% for SHL. Most of the increased disturbance on burned clearcuts was in the category "litter burned to mineral soil" (as differentiated from litter that was only partially consumed).

2. The category "litter burned to mineral soil" occurred on from 0 to 67% of the points surveyed between roads in burned clearcuts.

3. Gouges and deposits between roads were attributed, in order of frequency, to erosion (slumps, surface wash and gully), butt gouging, root overturns, skinning at the base of stumps and miscellaneous tractor blade disturbance.

Vegetative Cover

1. Vegetative cover increased steadily on all road surfaces with time since logging, reaching about 40% cover for main roads and 55% for other roads after 11 years.
2. Vegetative cover on unburned surfaces between roads reached about 72% cover, and on burned surfaces, about 63% 11 years following logging.
3. For burned clearcuts resurveyed after 1 year, vegetation cover doubled on and between roads. The percentage increase was much less in unburned clearcuts but, because of a higher residual vegetation component, the cover between roads remained higher than on the burned clearcuts.
4. Vegetative recovery after logging and broadcast burning was most rapid for clearcuts in the IDF Zone and IDF/ESSF Transition, and slowest in the IWH/ESSF Transition and the ESSF Zone.

Tree Regeneration

1. The major species of new regeneration were Douglas-fir and lodgepole pine in the IDF Zone, western hemlock and western red cedar in the IWH Zone, and subalpine fir and Engelmann spruce in the ESSF Zone. Subalpine fir was the major species of advance regeneration, particularly in the higher elevations.
2. Excluding 0- and 1-year clearcuts, mil-acre stocking levels of new regeneration were highest on roads (38.7%) and between roads (33.5%) in the IWH Zone, and lowest on roads (4.1%) and between roads (8.5%) in the IDF/ESSF Transition. Total stocking (new and advance regeneration) was highest on roads (39.8%) and between roads (38.5%) in the IWH Zone, and lowest on roads (6.1%) and between roads (11.9%) in the IDF/ESSF Transition.
3. Particularly in the oldest group of clearcuts, road surfaces had higher stocking levels of new regeneration than areas between roads.
4. Of all surfaces, total stocking was highest on areas between roads in unburned clearcuts.
5. Of the three types of road surfaces, stocking of new regeneration was highest on cutbanks, and lowest on sidecast.

6. Excluding planting, areas between roads in unburned clearcuts and road surfaces in burned and unburned clearcuts were satisfactorily restocked (over 30% of mil-acre plots with acceptable advance or new regeneration) after about 9 years. Surfaces between roads in burned clearcuts remained unsatisfactorily restocked up to 10.5 years, the average age of the oldest group of burned clearcuts.

Slash Cover

1. Unburned clearcuts had more than twice the cover of small-diameter slash on roads, and more than three times as much between roads as burned clearcuts. The cover of larger diameter slash (over 5 cm) was also greater on unburned clearcuts, but not to the same degree as for the small slash.
2. The greatest slash cover between roads occurred in the WGY(u) clearcut (62.1%), followed by SGY (u) (51.7%) and WHL(u) (50.0%) clearcuts. The least occurred in SHL(b) (11.6%), WGS(b) (20.7%) and SGS(b) (22.3%) clearcuts.

Erosion and Mass Wasting

1. Erosion was associated with the largest percentage of gouges and deposits between roads. In most cases, predisposition probably occurred as a result of exposure of mineral soil during yarding or severe burning.
2. Other examples of erosion and mass wasting encountered were surface water flow on roads and resulting channeling and gullying, road-edge cracks, fill-slope failures, cutbank slumping, slides and sedimentation. Some of these were encountered on transects and were thus recorded quantitatively; others were documented but not quantified.

Recommendations for Surveys and Research

1. Surveys and research are required to quantify the effects of the various types and degrees of soil disturbance on tree survival and growth, and on water quality over a range of ecosystem types for each biogeoclimatic zone. Procedures should be developed to ameliorate significant adverse effects.

INTRODUCTION

Widespread concern over the amount of soil disturbance associated with clearcut logging on steep slopes in the Nelson Forest District led in June, 1973, to the issuing by the B.C. Forest Service of guidelines which generally prohibited ground skidding on slopes over 70% and restricted its use on slopes between 50 and 70%. Reasons given for instituting the restrictions included the possibility that ground skidding on steep slopes was damaging to the soil, the basic resource of the forest, and to drainage patterns. Such restrictions in the mountainous Nelson Forest District implied a considerable shift from conventional ground skidding operations to those employing high-lead, grapple or other cable systems. Because of the enormous costs involved in a major change to cable systems, forest products companies in the District requested that a multi-agency committee be formed to examine the whole problem. To this end, the Steep Slope Committee was formed in early 1974. It consists of representatives from the B.C. Forest Service, Interior Lumber Manufacturer's Association, Forest Engineering Research Institute of Canada, B.C. Environment and Land-Use Committee Secretariat, and Canadian Forestry Service (Pacific Forest Research Centre and Western Forest Products Laboratory). The major objectives of the Committee are to initiate, undertake, coordinate, support and assist research on logging in mountainous terrain. One of the first problems was to determine more clearly the extent and nature of soil disturbance associated with logging in the District, relate such disturbance to logging method, and measure post-logging vegetation recovery. The Pacific Forest Research Centre agreed to conduct a general survey to obtain this information. In April, 1974, a plan for the survey was developed and circulated for comments. Members of the Interior Lumber Manufacturer's Association prepared lists of logged areas suitable for study. Field work was initiated in the summer of 1974 and continued in the summer of 1975.

METHODS

Study Procedures

The survey employed line transects with both point and mil-acre (.0004 ha) plot observations made at 3-m intervals. In general, procedures followed those of Garrison and Rummell (8), Dyrness (5) and Bockheim *et al.* (2), with modifications designed to increase the kinds of data collected. The start of the



Fig. 1. A 1-year-old, summer, ground skidded clearcut. The location of the transect is indicated by the white line.



Fig. 2. Skidroad cutbank with nylon chain and mil-acre stick marking the sample point. This point would be categorized as a "very deep gouge".

transect was usually located at the bottom of the clearcut and a direction was selected so that the line angled slightly off from a right-angle crossing of the contours (Fig. 1). Points and plot centres were located by means of a nylon chain equipped with metal tabs. When the chain was located above the ground surface, a stick, used to establish the radii (1.14-m long) of mil-acre plots, was employed as a plumb in establishing the point directly under the chain marker (Fig. 2).

Point observations were made for soil disturbance as follows:

- L = litter disturbed
- SM = mixture of mineral soil and humus
- SG = shallow gouge (mineral soil exposed to 5-cm depth)
- DG = deep gouge (5- to 25-cm depth)
- VDG = very deep gouge (over 25-cm depth)
- SD = shallow deposit (mineral soil deposited up to 5-cm depth)
- DD = deep deposit (5- to 25-cm depth)
- VDD = very deep deposit (over 25-cm depth)
- LBO = litter burned down to mineral soil.

Where possible, the cause of disturbance was indicated as, for instance, skidroad, skidroad sidecast, main road cutbank, butt gouge and surface erosion. Bedrock or boulders (over 60-cm diameter), windfalls, stumps and slash were recorded if present at the point. Slash was classified as small (less than 5-cm diameter) or large (more than 5-cm diameter). Each point was registered as burned or unburned and the slope and aspect at the point was measured.

Vegetative cover (including trees) was estimated for a mil-acre plot surrounding each point, using the following categories:

- 0 = 0%
- 1 = 1-20%
- 2 = 21-40%
- 3 = 41-60%
- 4 = 61-80%
- 5 = 81-100%.

The major plant species were listed but these data have not been summarized for this report.

Tree regeneration was assessed on each mil-acre plot on the basis of species, number and whether new (established since logging) or advance. Trees were included as advance regeneration if they were estab-

lished before logging and were less than 7.5-cm dbh. The latter limit was chosen as the safe upper limit for decay risk for subalpine fir, a major component of advance regeneration (16). Advance regeneration with poor form, e.g., sparse foliage, broken tops, distorted boles, large or numerous scars, was classified as "poor" and the rest as "good". Planted trees were recorded, but were kept separate from natural regeneration. No attempt was made to estimate mortality.

Some incidental observations, made independently of the transects, included gullying, mass wasting (slides and slumps), road and bridge washouts and debris in streams.

Thirteen transect segments surveyed in 1974 were rerun in 1975 to determine changes in vegetative cover.

Study Areas

The areas suggested by the forestry operators covered a wide range of soils, elevations and climates, and were included in several biogeoclimatic zones. The clearcuts represented a variety of logging systems, a range of logging ages and differences in post-logging treatment. They were distributed widely throughout the Nelson Forest District (Fig. 3).

Maps and historical data pertaining to the clearcuts were provided by the British Columbia Forest Service and forest companies. The following information was obtained for each cutover:

- year of logging
- method of felling
- method of yarding
- season of year of yarding
- snow condition at time of logging
- original stand composition
- post-logging treatment, e.g., slash disposal
- if planted, species used and year.

No attempt was made to determine the effects of variations in the efficiency of operations or adequacy of supervision.

Soil and landform data were supplied by the B.C. Land Inventory Program for areas covered by its surveys.

Seventy-eight transects were surveyed, on which

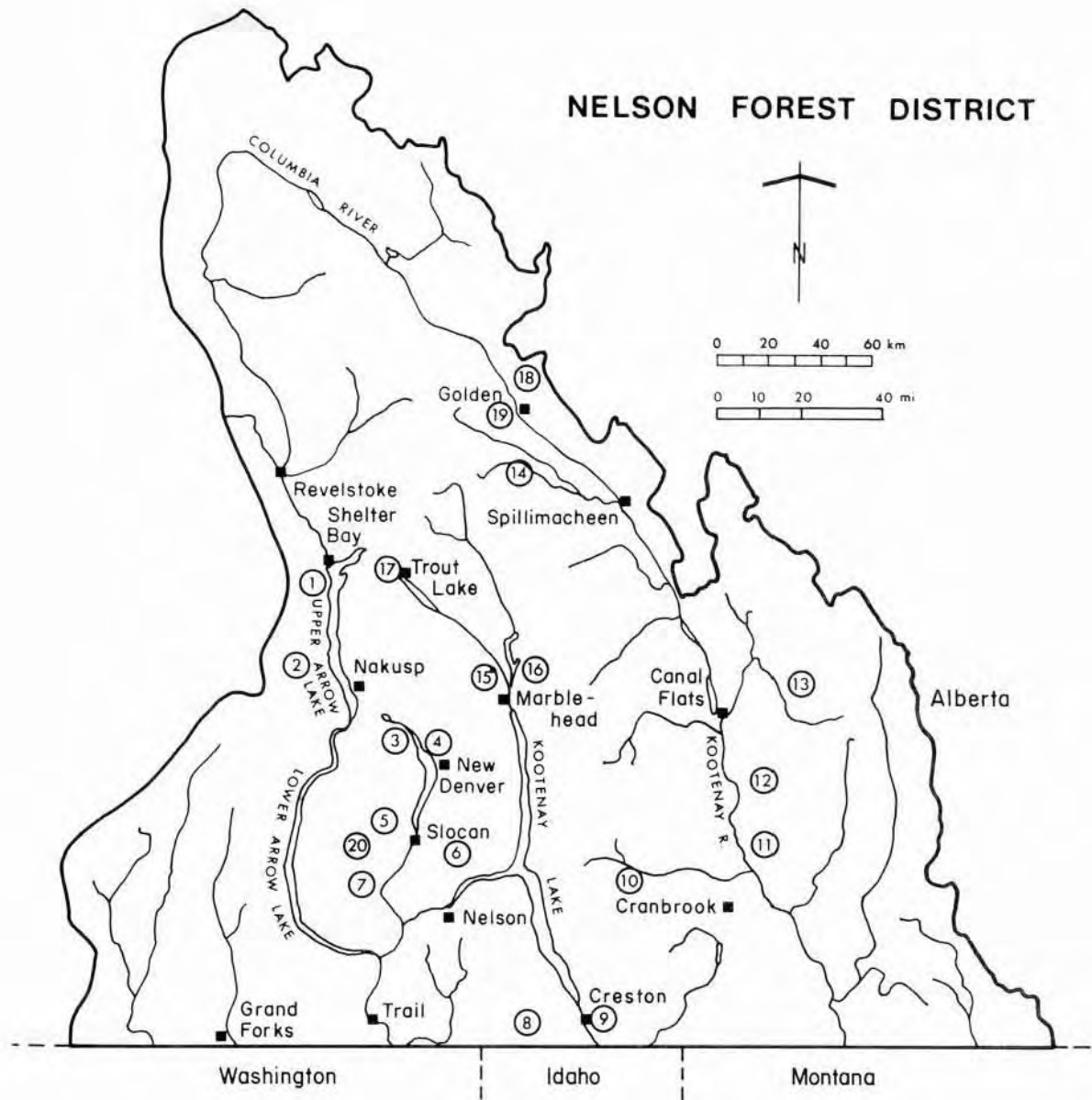


Fig. 3. Map of survey area. Circled numbers refer to drainages sampled: 1 - Pingston and Dry Cr; 2 - Cusson, Plant and Vipond Cr; 3 - Shannon Cr; 4 - Hicks Cr; 5 - Hoder Cr; 6 - Lemmon and Duhamel Cr; 7 - Airy Cr; 8 - Char Cr; 9 - Sullivan Cr; 10 - Sinclair Cr; 11 - E. Fork Wildhorse Cr; 12 - Lussier Cr; 13 - Elk and Grave Cr; 14 - Bobbie Burns Cr; 15 - Mat and John Cr; 16 - Glacier Cr; 17 - Batys Cr and Staubert Lk; 18 - Blaeberry Cr; 19 - Gorman Cr; 20 - Grizzly Cr.

Table 1. Percentage of clearcut area disturbed by all types of roads

Logging method	No. of points	Area disturbed by roads - %
Summer ground skidding (unburned) (SGS(u))	3,120	41.9
Summer ground skidding (burned) (SGS(b))	1,873	36.4
		} 39.8
Winter ground skidding (unburned) (WGS(u))	709	24.5
Winter ground skidding (burned) (WGS(b))	908	18.8
		} 21.3
Summer high-lead (unburned) (SHL(u))	1,099	9.0
Summer high-lead (burned) (SHL(b))	608	15.0
		} 11.1
Winter high-lead (unburned) (WHL(u))	220	16.4
Summer grapple yarding (unburned) (SGY(u))	199	27.1
Winter grapple yarding (unburned) (WGY(u))	142	21.8
Summer jammer yarding (unburned) (SJY(u))	181	7.7
Summer skyline (unburned) (SSL(u))	302	0.0

9,361 point and mil-acre plot observations were made. Because of changes in year or season of logging, logging method or in slash burning pattern along the transects, some were subdivided, with the result that 121 transect segments were separated and summarized independently.^{1/} In addition to the original survey, 1,628 points on 13 transect segments were resurveyed after 1 year to assess changes in vegetative cover. These were logged in 1973 and were left unburned (8 transects, 883 points) or logged and then burned in 1972 or 1973 (5 transects, 745 points).

^{1/} Mimeographed copies of the basic data for all transects may be obtained on request from the Pacific Forest Research Centre.

Twenty-seven drainages were sampled (Fig. 3). These were in three Tree Farm Licences (No. 3 - Triangle-Pacific Forest Products, No. 14 - Crestbrook Forest Industries and No. 23 - Canadian Cellulose Co.) and six Public Sustained Yield Units (Slocan, Creston, Cranbrook, Upper Kootenay, Kinbasket and Lardeau).

Three major biogeoclimatic zones (10) were represented: Interior Douglas-fir (IDF) - eastern, upper-elevation elements, Interior Western Hemlock (IWH) - mid- to upper-elevation elements, and Engelmann Spruce - Subalpine Fir (ESSF). In addition, transitions between the IDF and ESSF, and the IWH and ESSF Zones were recognized.

Elevations ranged from 838 to 1,905 m, with an aver-



Fig. 4. A summer skidroad. Note the very deep disturbance necessary on steep slopes to provide a safe, stable running surface for skidders.



Fig. 5. Soil disturbance caused by summer-built main (haul) roads and skidroads. Note the substantial proportion of the area covered by sidecast, roadbeds and cutbanks.

age of about 1,400 m. The average slope of transect segments varied from 30 to 81% (weighted average of 58.5%).

Eleven logging method/post logging treatment combinations were sampled (Table 1). The major emphasis, however, was placed on SGS(b), SGS(u), WGS(b), WGS(u), SHL(b) and SHL(u).

RESULTS

Soil Disturbance - Roads (including skidroads)

The percentages of clearcuts affected by all types of roads are shown in Table 1. SGS (Figs. 4 and 5) resulted in about twice as much soil disturbance by roads as WGS. SHL had about half as much disturbance as WGS or a quarter of SGS. GY caused a higher disturbance from roads than expected, somewhat higher than WGS but still considerably less than SGS. Two old SJY clearcuts had low road associated disturbance, while none was encountered on the SSL clearcut.

Most of the road disturbance on GS clearcuts was caused by skidroads, and most on HL clearcuts by main roads (Table 2). A high proportion of the

road disturbance on GY clearcuts was caused by the tail-hold roads, which varied in width but were often much wider than average summer-built skidroads. The fact that no main roads were registered for the GY clearcuts is a result of the low intensity of sampling in this group; that is, no haul roads were by chance crossed by transects on the two clearcuts surveyed. The WHL clearcut had a fairly high percentage of disturbance, including some caused by tractor roads. The purpose of these roads was not determined.

Skidroad beds made up the greatest proportion of disturbance on SGS clearcuts, followed by skidroad sidecast and skidroad cutbanks (Table 2). In contrast, on WGS clearcuts, most road-related disturbance was associated with skidroad sidecast, followed by skidroad beds and skidroad cutbanks. Winter skidroad beds tended to be much narrower than those built in the summer (Fig. 6) and sometimes short sections of the roadbeds were entirely absent. In HL clearcuts, main road sidecast caused the most disturbance, while in GY clearcuts, tail-hold roadbeds and sidecast were about equally represented.

Nearly 99% of the disturbance caused by roads was categorized as gouges or deposits (Table 3). Sidecast was invariably a deposit, cutbanks were gouges, and roadbeds were composed of both categories. Main road disturbance was evenly split between

Table 2. Type and extent of road disturbance occurring for each major logging method and season

Logging method	Road type ^{a/}															
	MR	MRSC	MRCB	SR	SRSC	SRCB	TH	THSC	THCB	CT	CTSC	CTCB	L	LSC	LCB	Total
	% of clearcut area															
Summer ground skidding	2.5	3.8	1.3	15.8	10.9	4.8	0.0	0.0	0.0	0.1	0.0	0.0	0.5	0.1	0.1	39.9
Winter ground skidding	1.1	1.2	0.6	6.4	9.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.1	0.1	21.3
Summer high-lead	1.8	3.4	1.4	0.8	1.1	0.1	0.0	0.0	0.0	0.3	0.2	0.0	0.9	0.9	0.2	11.1
Winter high-lead	0.5	4.5	0.0	1.4	2.7	0.9	0.0	0.0	0.0	5.9	0.0	0.5	0.0	0.0	0.0	16.4
Summer grapple yarding	0.0	0.0	0.0	0.0	0.0	0.0	12.6	13.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	27.1
Winter grapple yarding	0.0	0.0	0.0	1.4	1.4	0.0	11.2	7.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.8
Summer jammer yarding	1.1	1.7	2.1	2.2	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.7
Summer skyline	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

^{a/} MR = Main road (any truck road)
 SR = Skidroad
 TH = Tail-hold road
 CT = Miscellaneous tractor trails

L = Landing
 SC = Sidecast
 CB = Cutbank



Fig. 6. A winter-built skidroad. Note that the roadbed is much narrower (see 1.14-m stick in centre of picture) than normal summer skidroads

Table 3. Intensity of disturbance (gouges and deposits) for each road type (all transects)

	Road type ^{b/}														
Intensity ^{a/}	MR	MRSC	MRCB	SR	SRSC	SRCB	TH	THSC	THCB	CT	CTSC	CTCB	L	LSC	LCB
	%														
Shallow	0.0	9.3	3.8	7.7	19.0	10.4	7.3	8.1	0.0	61.9	33.3	100.0	10.6	9.1	0.0
Deep	0.6	15.3	4.8	19.1	21.0	20.1	36.6	27.0	0.0	9.5	33.3	0.0	14.9	31.8	0.0
Very deep	99.4	75.1	87.6	71.6	59.2	67.0	56.1	64.9	100.0	19.0	0.0	0.0	72.3	59.1	100.0
Shallow	5.3			12.3			7.4			60.0			9.0		
Deep	8.7			19.9			30.9			12.0			17.9		
Very deep	85.1			66.2			61.7			16.0			71.8		
Shallow								11.1							
Deep								17.8							
Very deep								69.8							

^{a/} Shallow = < 5 cm
 Deep = 5-25 cm
 Very deep = > 25 cm

^{b/} MR = Main road (any truck road)
 SR = Skidroad
 TH = Tail-hold road
 CT = Miscellaneous tractor trails
 L = Landing
 SC = Sidecast
 CB = Cutbank

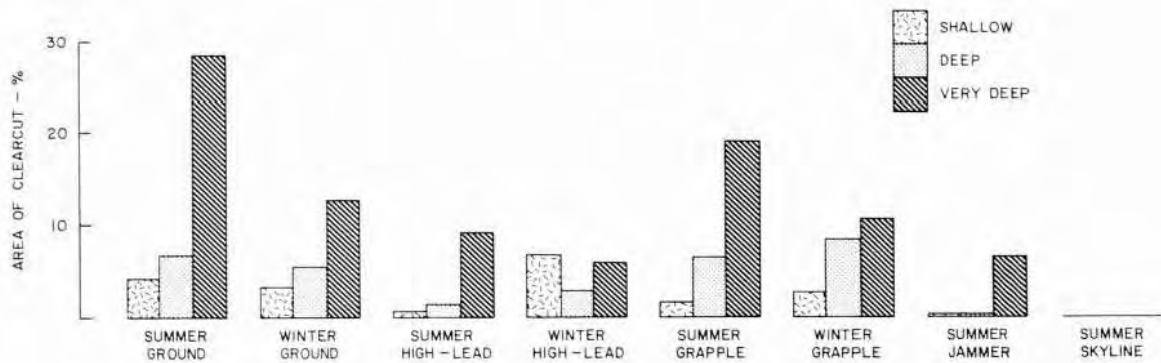


Fig. 7. Extent and degree of road-related soil disturbance for logging method/post-logging treatment combinations.

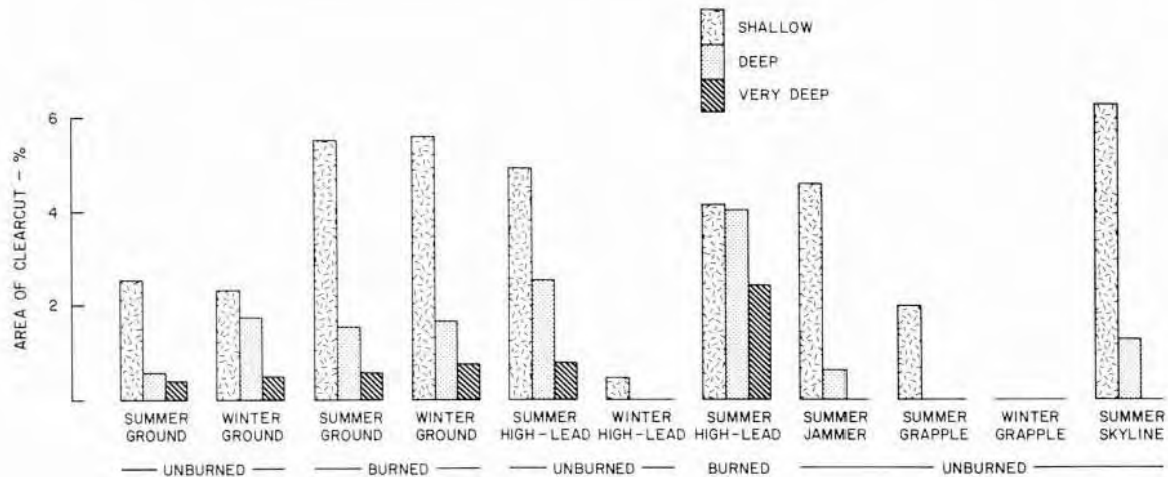


Fig. 8. Extent and degree of soil disturbance between roads excluding category "litter burned to mineral soil" for logging method/post-logging treatment combinations.

gouges and deposits. Skidroads were composed of more gouges (65%) than deposits (35%), as were tail-hold roads (76 and 24%).

Main roads had a higher proportion of very deep disturbance categories than skidroads (Table 3). The main roadbeds were nearly 100% very deeply disturbed compared to about 72% for skidroad surfaces. Tail-hold roads were shallower (56% very deep) than skidroads. The miscellaneous tractor roads were the shallowest (19% very deep). Winter-built skidroads, including sidecast and cutbanks, had a lower proportion of the very deep disturbance class-

ification (54.7%) than summer built (68.5%). For all road types, SGS produced 71% very deep disturbance and WGS only 60%. When these percentages are applied to Table 2, the difference between SGS and WGS becomes more apparent; that is, very deep disturbance from road construction occurred on 28.3% of SGS clearcuts and only 12.8% of WGS clearcuts (Fig. 7). SHL had less very deep disturbance from road construction (9.1%) and WHL even less (5.9%). GY had more very deep disturbance (19.1% for SGY and 10.6% for WGY) than SHL, while SJY was low (6.6%). No road disturbance was associated with the SSL clearcut.

Table 4. Extent and severity of disturbance between roads excluding the "litter burned to mineral soil" category

Logging method	Soil disturbance ^{a/}								Total gouges and deposits	
	L	SM	SD	SG	DD	DG	VDD	VDG		
	----- % of clearcut area -----									
Summer ground skidding (unburned)	1.0	0.0	1.3	1.3	0.2	0.4	0.2	0.2	3.6	} 3.9
Winter ground skidding (unburned)	1.1	0.0	1.3	1.1	0.9	0.9	0.1	0.4	4.7	
Summer ground skidding (burned)	1.6	0.2	1.7	3.9	0.9	0.7	0.3	0.3	7.8	} 8.1
Winter ground skidding (burned)	5.9	0.0	1.4	4.3	0.4	1.3	0.6	0.2	8.2	
Summer high-lead (unburned)	5.3	0.2	1.4	3.6	0.8	1.8	0.2	0.6	8.4	} 7.1
Winter high-lead (unburned)	0.9	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.5	
Summer high-lead (burned)	0.2	0.0	2.6	3.8	1.9	2.8	0.5	2.0	13.6	
Summer grapple yarding (unburned)	12.6	0.5	0.0	2.0	0.0	0.0	0.0	0.0	2.0	} 1.2
Winter grapple yarding (unburned)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Summer jammer yarding (unburned)	0.0	0.0	0.6	3.8	0.0	0.6	0.0	0.0	5.0	
Summer skyline (unburned)	5.7	1.0	2.7	3.6	0.3	1.0	0.0	0.0	7.6	

^{a/}

L = Litter disturbed
 SM = Shallow mixture
 SD = Shallow deposit
 SG = Shallow gouge

DD = Deep deposit
 DG = Deep gouge
 VDD = Very deep deposit
 VDG = Very deep gouge

Soil Disturbance - Between Roads

Soil disturbance between roads was generally caused by the yarding operation, by burning, or by one of these in concert with erosional forces. Including "litter disturbed", disturbance between roads was only about 5% for unburned SGS, WGS, WHL and SJY (Table 4). Burned clearcuts generally had a higher amount of disturbance between roads, much of which was in the category "litter burned to mineral soil". This category occurred on 12.0% of SGS(b) clearcuts, 24.9% of WGS(b) clearcuts and 45.4% of SHL(b) clearcuts. Even excluding the category "litter burned to mineral soil", disturbance was about one and one-half to three times greater for burned SGS, WGS and SHL than their unburned counterparts. Possibly this was due to increased post-burning erosion.

Except when conducted in the winter, cable logging generally caused more disturbance between roads than ground skidding. Total disturbance between roads on the SSL clearcut was fairly high (14.3%) (Table 4). However, none of this was categorized as very deep, only 1.3% as deep, and the remainder as shallow or merely litter disturbed or mixed.

Disturbance between roads consisted of a higher proportion of shallow than very deep disturbance (Fig. 8), the opposite of road disturbance (Fig. 7).

When only gouges and deposits are considered, disturbance between roads was highest for SHL(b), SHL(u), WGS(b), SGS(b) and SSL (Table 4). The fewest gouges and deposits were associated with winter, unburned operations.

The major causes suggested for gouges and deposits between roads, in order of frequency, were erosion



Fig. 9. The butt gouge, a type of soil disturbance found between roads that results when one end of a log drags across the ground. This is particularly a feature of cable-yarding operations.

(slumps, surface wash and gullyying), butt gouging (Fig. 9), root overturns, disturbance at the base of stumps (skinning) and miscellaneous tractor blade disturbance (Table 5). Much of the disturbance attributed to erosion may originally have been

Table 5. Recorded cause of deposits and gouges occurring between roads

Cause	Frequency - %				
	Burned	Unburned	Ground	Cable	All transects
Root overturn	17.8	20.4	33.3	11.0	19.4
Erosion	66.4	25.3	48.5	36.6	41.0
Butt gouge	0.0	51.2	1.0	50.0	31.6
Stump-root skinning	9.9	3.1	11.1	2.4	5.7
Tractor blade	5.9	0.0	6.1	0.0	2.3

Table 6. The relationship between soil disturbance by skidroads and slope steepness

Slope - %	Area disturbed by skidroads - %	
	Summer ground skidded	Winter ground skidded
29.9 - 39.9	47.1	18.8
40.0 - 49.9	29.9	9.8
50.0 - 59.9	28.9	13.1
60.0 - 69.9	35.2	28.1
70.0 - 81.0	25.1	25.8
	30.4	12.9
	33.3	26.8

Table 7. Average grade of skidroads and main roads for topographic slope classes

Slope - %	Skidroads		Main roads	
	Basic number	Average grade - %	Basic number	Average grade-%
29.9 - 39.9	106	24.8	22	9.3
40.0 - 49.9	119	22.0	22	11.6
50.0 - 59.9	303	18.6	54	11.4
60.0 - 69.9	228	20.7	51	10.7
70.0 - 81.0	71	14.9	15	7.4

yarding gouges and deposits, or areas on which the litter was burned off and mineral soil exposed. Burned clearcuts had a higher proportion of eroded points than unburned. Nearly 30% of eroded points were very deeply disturbed, while butt gouging was generally only deep or shallow. Butt gouges were associated mainly with cable yarding, though none were recorded in SHL(b) clearcuts. This absence might be a result of the greater erosion on burnt slopes and subsequent masking of original butt gouges.

Relationship between Slope Steepness and Road Disturbance

Within the range of slopes surveyed (29-81%), there was no apparent correlation between the amount of

disturbance caused by summer-built skidroads and degree of slope. However, for WGS, slopes averaging over 60% had over twice as much skidroad disturbance as those averaging less than 60% (Table 6).

Relationship between Skidroad Steepness and Slope Steepness

Skidroads did not increase in steepness with increasing topographic slope. Rather, the steepest average skidroads were found on the gentlest slopes sampled, while those with the lowest average grade occurred on the steepest slopes (Table 7). No relationship between topographic slope and main road steepness was apparent.

Vegetative Cover - Roads

To simulate vegetative cover with time following logging, clearcuts were grouped by age classes 0-1, 2-4, 5-8 and 9+ years. Vegetative cover increased steadily on all skidroad surfaces (roadbed, sidecast and cutbank) with increasing time following logging (Fig. 10), reaching nearly 60% cover 11 years after logging. Main roads lagged behind in cover, reaching less than 40% in 11 years. Except for a delay in the early stages, roads in burned clearcuts recovered about as quickly as in unburned clearcuts up to the maximum of 12 years sampled for burned clearcuts.

Vegetative Cover - Between Roads

Vegetative cover on unburned clearcuts was initially about 35% and increased to about 75% at an average of 15 years after logging (Fig. 11). Burned clearcuts had residual vegetative cover of less than 5%. This cover increased rapidly to about 65% in 10 years. Burned clearcuts lagged behind unburned by up to 4 years. On the average, the burned clearcuts never did attain as high a level of vegetative cover as the unburned clearcuts up to the maximum age of logging sampled. The lag on burned clearcuts was influenced by the interval between logging and slash burning which, in the District, averaged slightly over 1 year. The assumption is made that between the time of logging and burning, vegetative cover was about 35%, as found for the recent and 1-year-old unburned clearcuts. This cover would be reduced to less than 5% by burning, followed by the increase illustrated in Fig. 11.

Vegetative cover on unburned surfaces between roads was greater by about 30% than that on road-disturbed surfaces for the first 6 years. Subsequently, the rate of increase in vegetative cover on the latter areas exceeded that on the former so that the difference was only 15 to 20% in later years. Vegetative cover on burned areas between roads was consistently, though only marginally, higher than on road surfaces over the period of time that a comparison could be made.

Comparisons of vegetative cover between roads among biogeoclimatic zones were made by grouping clearcuts logged 3, 4 and 5 years previous to sampling (Table 8). These years were chosen because clearcuts within this range of ages were well represented in each of the zones and, if trends occurred, they would show up by this time. The highest post-logging

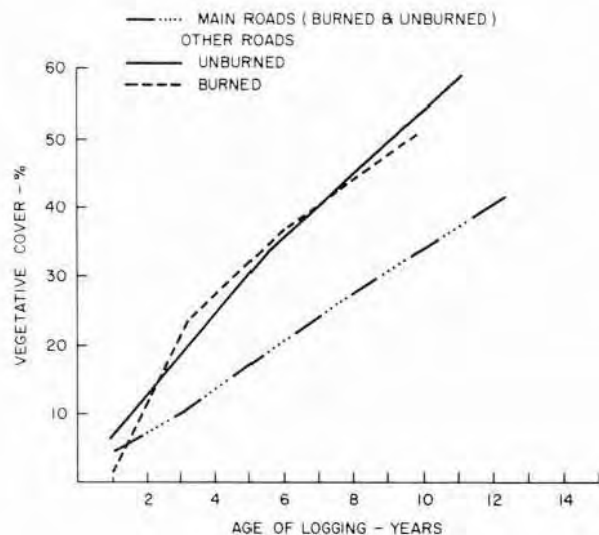


Fig. 10. Simulated trends in vegetative cover with time after logging on road surfaces for burned and unburned clearcuts.

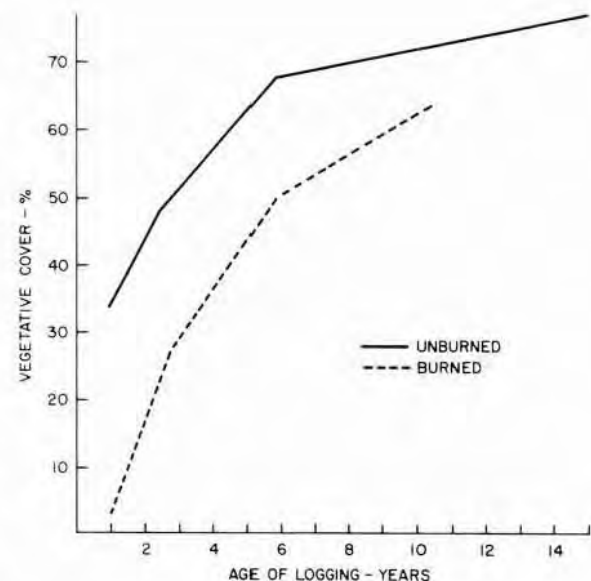


Fig. 11. Simulated trends in vegetative cover between roads with time after logging for burned and unburned clearcuts.



Fig. 12. Luxuriant grass - rich vegetation on calcareous soils in a 4-year-old clearcut in the Interior Douglas-fir Zone.

Table 8. Vegetative cover between roads in clearcuts logged 3, 4 and 5 years before sampling in five biogeoclimatic zones

Biogeoclimatic Zone	Average vegetative cover - %		
	Unburned	Burned	All clearcuts
Interior Douglas-fir	71.6	72.4	72.2
Interior Douglas-fir/Engelmann Spruce-Subalpine Fir	74.0	51.3	66.4
Interior Western Hemlock	59.6	38.9	48.4
Interior Western Hemlock/ Engelmann Spruce-Subalpine Fir	45.3	21.2	32.8
Engelmann Spruce-Subalpine Fir	65.5	28.4	41.5
Totals	62.4	34.6	45.6

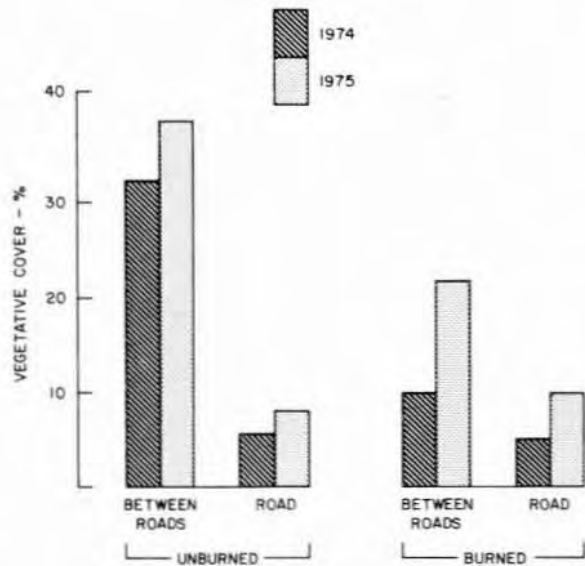


Fig. 13. Vegetative cover for burned and unburned resurveyed transects on and between roads - 1974 and 1975.

vegetative cover occurred in the IDF Zone (Fig. 12) and in the IDF/ESSF Transition. These two zones were also least affected by burning in that vegetative cover on burned clearcuts in the age range summarized was higher than for the other three zones. Slowest vegetative recovery after burning occurred in the ESSF Zone and the IWH/ESSF Transition (Table 8).

Vegetative Cover - Resurveyed Transects

The vegetative cover for transects resurveyed after 1 year is shown in Fig. 13. The change in cover represents changes during the period from 1 year after to 2 years after logging or burning. On both roads and between roads, the cover doubled in the 1 year on burned clearcuts but only increased marginally on the unburned clearcuts. The increase in vegetative cover on the unburned clearcuts was less than that indicated in the general vegetation recovery curve derived earlier for the same period of time (Fig. 11).



Fig. 14. Severe 1-year-old broadcast slash burn in winter-logged Engelmann spruce-subalpine fir cutover. Stumps were abnormally high due to very deep snow pack at the time of logging.



Fig. 15. Same clearcut as in Fig. 14 but 2 years after burn. Note increase in vegetative cover around stump in foreground and in centre of picture.



Fig. 16. Erosion on the clearcut illustrated in Figs. 14 and 15. The log has intercepted some of the eroded soil.

The increase in cover for the burned clearcuts was about the same as that indicated by the general curve for burned areas.

Two of the clearcuts resurveyed (Hoder and Char Cr) had been severely burned. While vegetation cover increased on these openings (Figs. 14 and 15), considerable surface erosion has occurred on both (Fig. 16). No surface erosion was noted on the resurveyed unburned clearcuts.

Species Composition of Tree Regeneration

Tree regeneration was classified as advance (established before logging), new (established since logging) and planted. Advance stems were classified as good or poor, depending on their condition, with the implication that only "good" stems should be considered acceptable for determining adequacy of stocking. There were 11 species of new and 8 of advance regeneration recorded (Table 9). Three of

the 8 advance species, i.e., birch, lodgepole pine and white pine, were only rarely encountered as advance regeneration. Western red cedar, western hemlock, Engelmann spruce and subalpine fir were the most common components of new regeneration, while subalpine fir was by far the most abundant advance species. New regeneration of cottonwood was almost completely restricted to road surfaces. Engelmann spruce was proportionally much more abundant on than between roads, while the reverse was true for western hemlock and subalpine fir.

The composition of tree regeneration clearly differed among biogeoclimatic zones (Table 10). New regeneration in the IDF Zone was composed of shade intolerant pioneers such as cottonwood, lodgepole pine, aspen and birch and the climax tree for this Zone, Douglas-fir. The latter was the chief component of advance regeneration. The IDF/ESSF Transition contained much the same species of new regeneration, but also a large proportion of subalpine fir, Douglas-fir and Engelmann spruce. Ten of the 11 species of new regeneration were recorded in the IWH Zone but

Table 9. Species composition of advance and new regeneration (all transects)

Regeneration	Species ^{a/} - %										
	A	Cot	Bi	Pl	L	F	Pw	C	H	Se	Bs
Advance Roads	0	0	0	0	0	4.7	0	26.4	9.9	11.3	47.7
Between roads	0	0	0.3	0.3	0	9.8	0.4	21.5	16.7	5.3	45.7
New Roads	2.2	4.9	1.0	1.4	0.4	10.0	2.5	29.6	14.5	22.4	11.1
Between roads	2.6	0.1	1.7	2.8	0.4	8.2	4.1	24.6	23.8	12.4	19.3

^{a/} A = Aspen	Pw = Western white pine
Cot = Cottonwood	C = Western red cedar
Bi = Birch	H = Western hemlock
Pl = Lodgepole pine	Se = Engelmann spruce
L = Western larch	Bs = Subalpine fir
F = Douglas-fir	

western red cedar and western hemlock dominated. Engelmann spruce was fairly common as new regeneration but seldom as advance. Advance regeneration was mainly western red cedar, western hemlock and subalpine fir. New regeneration in the IWH/ESSF Transition was dominated by cedar, hemlock, subalpine fir and Engelmann spruce. The first three of these were the dominant advance regeneration species. All 11 species of new regeneration occurred to some extent in the ESSF Zone but Engelmann spruce and subalpine fir were by far the most common. Subalpine fir dominated the advance regeneration component.

Stocking Levels of Tree Regeneration

Stocking levels were computed on a mil-acre basis for new and advanced regeneration (good and poor) on and between roads. Each mil-acre plot was considered stocked with new regeneration if at least one tree 1 year of age or older, established since logging, was present. It was considered stocked with advance regeneration if at least one tree established before logging and less than 7.5-cm dbh was present. Total stocking was computed by adding mil-acre plots stocked with new regeneration and any additional plots stocked only with advance regeneration. Planted trees were tallied but were not included in the stocking calculations.

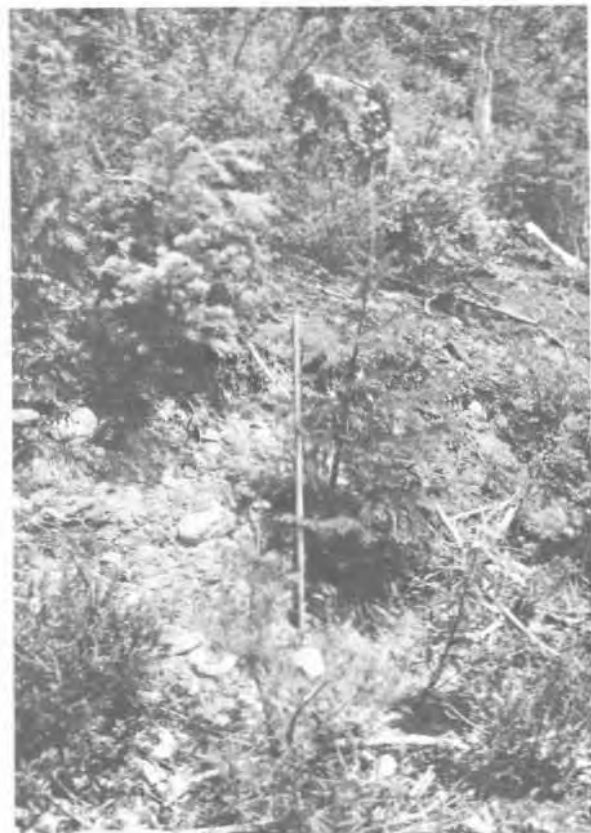


Fig. 17. Stocking of new regeneration of Douglas-fir and western white pine on skidroad cutbank in 10-year-old clearcut in Western Hemlock Zone.

Table 10. Species composition of new and advance regeneration in each biogeoclimatic zone.

Biogeoclimatic Zone or Transition ^{a/}	Species ^{b/} - %										
	A	Cot	Bi	Pl	L	F	Pw	C	H	Se	Bs
IDF ZONE											
New-roads	6.4	9.3	5.0	11.4	0.7	60.8	0	0	0	6.4	0
-between roads	27.3	0	6.3	22.4	0	41.9	0.7	0	0	1.4	0
Advance-roads	0	0	0	0	0	0	0	0	0	0	0
-between roads	0.4	0	3.2	2.8	0	91.2	0	0	0	2.4	0
IDF/ESSF TRANS.											
New-roads	0	0	0	23.1	0	0	0	0	0	15.4	61.5
-between roads	3.3	0	0	13.3	3.3	20.0	0	0	0	6.7	53.4
Advance-roads	0	0	0	0	0	20.0	0	0	0	0	80.0
-between roads	0	0	0	0	0	18.2	0	0	0	13.6	68.2
IWH ZONE											
New-roads	0.7	6.5	1.0	0	0.3	8.7	1.5	43.5	20.0	13.8	4.0
-between roads	0.4	0.1	2.0	0	0	8.2	3.9	34.1	35.7	8.3	7.3
Advance-roads	0	0	0	0	0	0	0	63.9	19.4	0	16.7
-between roads	0	0	0.2	0	0	0	0	45.5	44.6	1.1	8.6
IWH/ESSF TRANS.											
New-roads	2.4	0.8	0	0	0	6.5	5.7	22.8	19.5	31.7	10.6
-between roads	0.5	0.5	0.5	0	3.7	3.7	8.3	33.8	13.3	21.5	14.2
Advance-roads	0	0	0	0	0	14.5	0	48.4	19.4	3.2	14.5
-between roads	0	0	0	0	0	2.5	0.5	42.3	26.1	3.6	25.0
ESSF ZONE											
New-roads	5.6	0.2	0.2	2.5	0.4	1.2	5.4	0.6	2.1	48.7	33.1
-between roads	3.2	0	0	6.1	0.4	0.5	3.9	2.0	2.1	23.4	58.4
Advance-roads	0	0	0	0	0	0	0	2.8	1.8	20.2	75.2
-between roads	0	0	0	0.1	0	1.2	0.6	5.0	3.1	8.5	81.5

^{a/}

IDF = Interior Douglas-fir
 IWH = Interior Western Hemlock
 ESSF = Engelmann Spruce-Subalpine Fir
 TRANS. = Transition

^{b/}

A = Aspen
 Cot = Cottonwood
 Bi = Birch
 Pl = Lodgepole pine
 L = Western larch
 F = Douglas-fir

Pw = Western white pine
 C = Western red cedar
 H = Western hemlock
 Se = Engelmann spruce
 Bs = Subalpine fir

Table 11. Stocking of new and advance regeneration on all burned and unburned clearcuts

	Burned		Unburned	
	Roads	Between roads	Roads	Between roads
	----- % stocking -----			
New regeneration	19.8	11.9	13.2	10.8
Advance regeneration	0.9	4.2	6.4	23.3
Total	20.7	16.1	19.6	34.1
Total stocking (minus common plots)	20.4	14.8	18.8	30.2
Weighted average age of logging (years)	5.4	5.1	3.6	5.5

Stocking levels for all transects are shown in Table 11. Roads had a higher stocking of new regeneration than between roads (Fig. 17), particularly on burned clearcuts. Stocking of new regeneration on road surfaces was higher on burned clearcuts than on unburned. However, the average age of the unburned clearcuts was less than the burned, so the real difference is not as great as indicated (Table 11). There was little difference in stocking of new regeneration between burned and unburned surfaces between roads. Comparing all surfaces, total stocking was highest between roads in unburned clearcuts.

To simulate trends in stocking with time and thus eliminate the age differences noted in Table 11, the data were combined into four groups based on years following logging—0-1, 2-4, 5-8 and 9+ years. The weighted logging age of each group was computed and used in the construction of the graphs. As with vegetation recovery, the graphs do not represent observations over time, but rather a comparison of clearcuts of varying logging ages. On both burned and unburned clearcuts, natural new regeneration increased with time following logging (Figs. 18 and 19). Except for a lag in the early years, burned surfaces between roads regenerated about as quickly as unburned ones (Fig. 18). The trend was for greater stocking of new regeneration on roads in unburned clearcuts for the oldest ones studied (Fig. 19). Roads were more conducive to the establishment of new regeneration than surfaces between roads, the difference being most evident in the older clearcuts (compare Figs. 18 and 19).

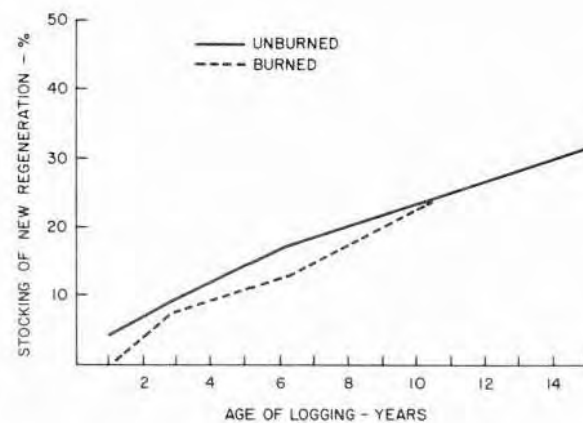


Fig. 18. Simulated trends in mil-acre stocking of new regeneration between roads with time after logging for burned and unburned clearcuts.

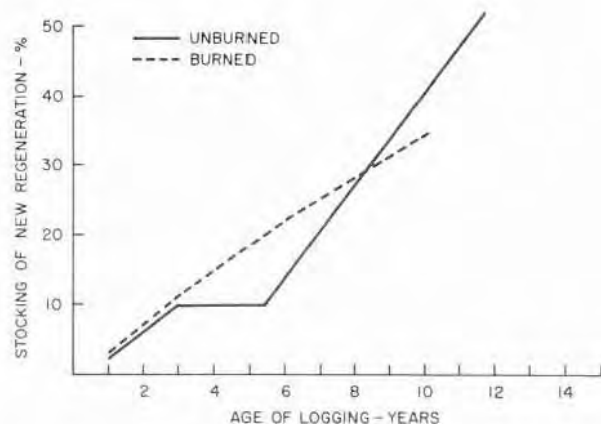


Fig. 19. Simulated trends in mil-acre stocking of new regeneration on road surfaces with time after logging in burned and unburned clearcuts.

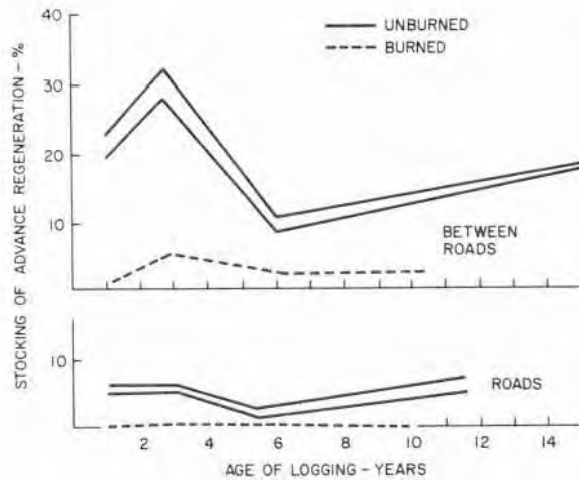


Fig. 20. Simulated trends in mil-acre stocking of advance regeneration with time after logging on and between roads for burned and unburned clearcuts. The lower solid line of each pair excludes "poor" advance stems.

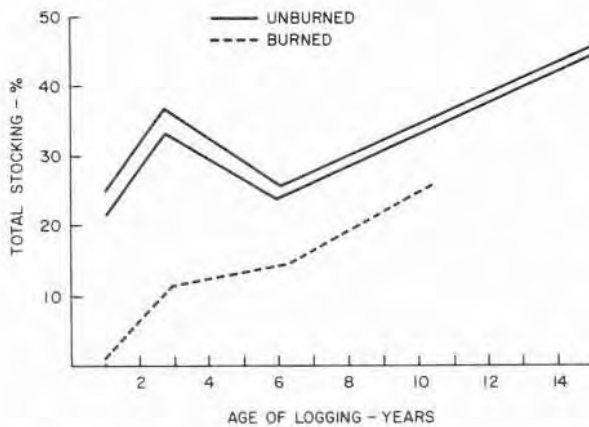


Fig. 21. Simulated trends in total mil-acre stocking (new regeneration plus any other plots stocked only with advance regeneration) between roads with time following logging for burned and unburned clearcuts. The lower solid line excludes "poor" advance stems.

Fig. 22. Simulated trends in total mil-acre stocking (new regeneration plus any other plots stocked only with advance regeneration) on roads with time following logging for burned and unburned clearcuts. The lower solid line excludes "poor" advance stems.

If one could follow a number of clearcuts over a long period of time, stocking of advance regeneration should remain steady or decline slightly with time. In this survey, advance regeneration varied erratically with age of clearcut (Fig. 20). Advance regeneration was an important component between roads on unburned clearcuts, but was understandably of much less common occurrence on roads and on burned clearcuts between roads (Fig. 20).

Total stocking remained higher between roads on unburned than on burned clearcuts for at least 10 years after logging (Fig. 21). Differences in total stocking on roads between those in burned clearcuts and those in unburned clearcuts were not apparent except for a higher total stocking in the oldest unburned clearcuts (Fig. 22).

In general, unburned surfaces between roads and all road surfaces (roadbed, cutbank and sidecast combined) could be considered satisfactorily stocked (i.e., over 30% mil-acre stocking) with new and advance regeneration at about 9 years following logging. In contrast, burned areas between roads remained unsatisfactorily restocked up to 10.5 years, the average age of logging of the oldest group of burned clearcuts. These results do not include planted trees, which were tallied but kept separate from natural regeneration.

The season of logging appeared to have some effect on the rate of stocking of new regeneration on roads (Table 12). WGS roads generally had a higher stocking of new regeneration than SGS roads. The difference showed up particularly on main road and skidroad sidecast (Table 13).

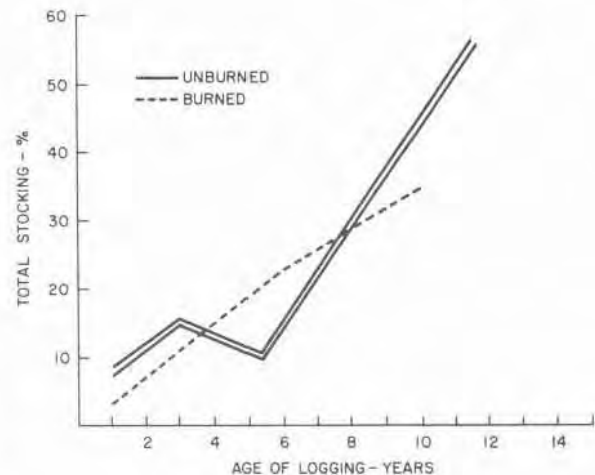


Table 12. Stocking levels of new regeneration for summer and winter logging (burned and unburned)

	Years following logging			
	0-1	2-4	5-8	9+
	----- % stocking -----			
Unburned, summer ground skidding				
- roads	3.0	10.5	6.4	49.7
- between roads	8.5	12.6	10.8	40.6
Unburned, winter ground skidding				
- roads	2.4	13.5	12.5	50.0
- between roads	3.7	10.9	36.5	28.6
Burned, summer ground skidding				
- roads	No data	11.8	19.5	28.2
- between roads	No data	17.9	12.4	16.3
Burned, winter ground skidding				
- roads	No data	17.4	65.2	41.0
- between roads	No data	1.0	17.7	43.9

Table 13. Stocking levels of new regeneration on different road surfaces for summer and winter logging

	Road surface types ^{a/}									
	MR	MRSC	MRCB	SR	SRSC	SRCB	O	OSC	OCB	All
	----- % stocking -----									
All summer logging	17.6	8.8	36.8	18.4	8.5	18.4	19.2	2.0	20.0	15.2
All winter logging	27.8	20.0	30.0	20.4	13.0	25.0	5.6	7.7	33.3	17.0

^{a/} MR = Main road (any truck road)
 SR = Skidroad
 O = Other (tail-hold and miscellaneous tractor roads, landings)

SC = Sidecast
 CB = Cutbank

Stocking of new regeneration was consistently lower on sidecast than on cutbanks or roadbeds (Table 14). Stocking of advance regeneration on roads was low, as noted earlier, being highest on sidecast and lowest on the roadbeds.

The highest stocking of new regeneration occurred in the IWH Zone, both on and between roads (Table 15). For the latter, especially, this was far above the stocking for any other zone. Taking the average age of the clearcuts into account, high stocking was also found on roads in the IDF Zone. The lowest stocking

of new regeneration occurred both on and between roads in the IDF/ESSF Transition. Relative to average logging age, fairly low stocking was also experienced between roads in the IDF Zone (Table 15).

The highest stocking of advance regeneration was found both on and between roads in the IWH/ESSF Transition (Table 15). The lowest was found on roads in the IDF Zone and between roads in the IDF/ESSF Transition.

The best total stocking occurred on and between

Table 14. Stocking levels of new and advance regeneration on different road surfaces (%)

	Road surface types ^{a/}								
	MR	MRSC	MRCB	SR	SRSC	SRCB	O	OSC	OCB
New regeneration	18.6	10.0	36.2	18.6	9.4	19.4	14.7	3.2	23.1
Advance regeneration	0.0	4.3	1.9	2.9	7.1	5.0	2.8	8.1	15.4

^{a/} MR = Main road (any truck road)
 SR = Skidroad
 O = Other (tail-hold and miscellaneous tractor roads, landings)

SC = Sidecast
 CB = Cutbank

Table 15. Stocking levels in the five biogeoclimatic zones and transitions (0 - and 1-year-old logging omitted)

Biogeoclimatic Zone or Transition ^{a/}	Age of logging		Roads			Between roads		
	Roads	Between roads	New	Advance	Total ^{b/}	New	Advance	Total
	----- % -----							
IDF	6.1	9.8	26.1	0.0	26.1	15.8	20.6	31.9
IDF/ESSF	5.2	5.6	4.1	2.0	6.1	8.5	6.1	11.9
IWH	7.0	7.6	38.7	2.3	39.8	33.5	8.2	38.5
IWH/ESSF	5.9	5.6	16.1	9.7	24.0	11.6	22.5	30.2
ESSF	4.5	6.6	14.8	3.7	18.2	11.2	14.9	23.8

^{a/} IDF = Interior Douglas-fir
 IWH = Interior Western Hemlock
 ESSF = Engelmann Spruce-Subalpine Fir

^{b/} Total = New regeneration plus any other plots stocked only with advance regeneration



Fig. 23. An example, indicated by pen, of the category "litter burned to mineral soil". Patch of organic matter to right of pen was burned but would otherwise be categorized as "undisturbed".

roads in the IWH Zone. The lowest total stocking was found on and between roads in the IDF/ESSF Transition.

Intensity of Burns

Burning was recognized as an important factor in determining the amount of soil disturbance, vegetative cover and regeneration, particularly advanced regeneration, between roads. The intensity of burn varied greatly among areas. Most burns were the result of deliberate slash abatement measures but a few were wildfires or escaped slash fires followed by salvage logging.

Of the total number of points between roads on transects classified as burned, 80.7% were recorded as actually being burned; that is, even in burned areas, 19.3% of the area between roads was unaffected. Of all the points between roads that were actually burned, 39.1% were rated as severely burned (litter burned off and mineral soil exposed) (Fig. 23). Expressed another way, 31.0% of all points between roads on burned clearcuts were severely burned, 49.7% lightly burned and 19.3% not burned at all.

The amount of severe burning varied greatly from clearcut to clearcut. The percentage of points between roads in burned clearcuts that were actually burned varied from 29% in very spotty burns to 100% in uniform ones. The percentage of severely burned points varied from 0 in lightly burned clearcuts to 88 in severely burned clearcuts. There was no correlation of geographic location or biogeoclimatic zone with burn severity. Severely burned clearcuts (over 50% of burned points rated severely burned) occurred in widely separated drainages and often in the same ones as lightly burned clearcuts (less than 15% of burned points burned severely). There were, however, some differences between the two groups (Table 16). The severely burned group was steeper and rockier than the lightly burned and was covered by a generally more complete burn. Aspect was not clearly associated with burn intensity.

Two of the 13 severely burned clearcuts were burned over twice – the first, an escaped slash burn into standing timber, and the second, an escaped burn that occurred after the fire-killed timber was salvaged. Four of the 16 lightly burned transects were burned by wildfires and later salvaged. All other burned transect segments were, as far as could be ascertained, subjected to a single broadcast burn.



Fig. 24. Heavy slash load and high stumps 1 year after a winter, grapple-yarding operation in a western red cedar-western hemlock stand.

Table 16. A comparison of severely and lightly burned transects

	No. of transects	Severe burn-% <u>a</u> /	Points burned % <u>b</u> /	Slope %	Rock % <u>c</u> /
Severely burned	13	67.0	88.6	60.8	5.9
Lightly burned	16	9.2	72.5	54.1	3.2

a/ % of burned points between roads that were rated as litter burned to mineral soil

b/ % of points between roads that were burned

c/ % of area that was bedrock or boulders larger than 60-cm diameter

Slash Cover

Slash covered 21.5% of the road surfaces of all transects (Table 17). Of this, 9.3% was made up of slash less than 5-cm diameter and 12.2% with slash greater than 5-cm diameter. Burned clearcuts had less slash on roads than unburned, but the difference was only in the smaller slash – 4.8% cover on burned and 11.8% on unburned. The greatest slash cover on roads occurred in the WGY(u) clearcut (Fig. 24), followed by WGS(u), SHL(u) and WHL(u). The least occurred on SGY(u) (one clearcut only), SHL(b) and SGS(b). The highest slash loads occurred on the sidecast portion of all road types – skidroads, main roads and tail-hold roads (Fig. 25). For instance, slash cover on main road sidecast was 11.3 times that on the roadbed, and on skidroad sidecast was 2.5 times that on the skidroad bed.

Between roads, the overall slash cover was 32.9%, about evenly divided between small and large slash (Table 17). Burned clearcuts had a considerably reduced slash load (19.5%) compared with unburned (40.6%). The reduction in burned clearcuts was most pronounced in small slash, but a reduction also occurred in the larger material. The highest slash cover between roads occurred in the WGY(u) clearcut, followed by SGY(u), WHL(u), SSL(u) and SHL(u). The least slash between roads occurred in SHL(b) clearcuts, followed by WGS(b) and SGS(b).

Surface Erosion and Mass Wasting

In addition to the measurements made along the transects, incidental observations were made of some of the more conspicuous soil erosion problems. Surface water flow was particularly evident in early June at the peak of snow melt and was most commonly observed on roads (Fig. 26). The result of such flow was sometimes channeling in fine-textured soils (Fig. 27) or massive gullying in coarse-textured soils (Fig. 28). The gully depicted in Fig. 28 varied in width and depth and extended for about 1.5 km. The cause of the erosion was purportedly a blocked culvert that caused diversion of a stream down an existing road. Further investigation showed that skidding downhill in a concave basin above the main gully may have precipitated or at least aggravated the problem.

Surface erosion was associated with a considerable proportion of the gouges and deposits encountered

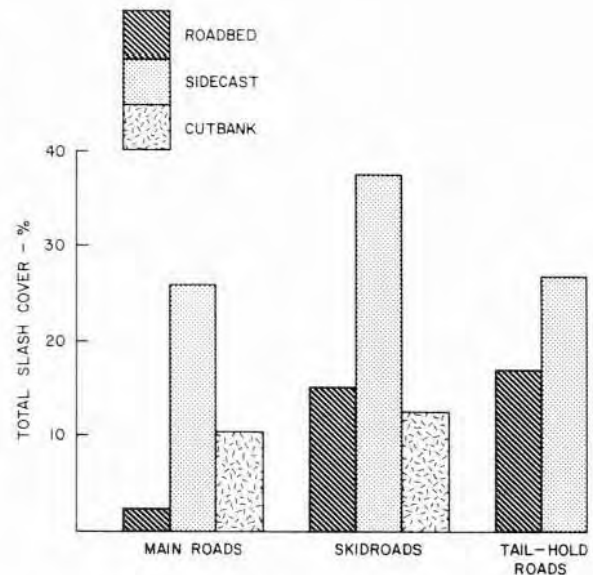


Fig. 25. Cover of slash on the three types of road surfaces for main roads, skidroads and tail-hold roads.



Fig. 26. Surface-water flow on a haul road during the peak of snow melt. Runoff from a burn above the road contributed to the dark appearance of the water.

Table 17. Slash cover on and between roads (all transects)

Logging method	Roads			Between roads			Total clearcut area		
	1 ^a /	2 ^b /	Tot.	1	2	Tot.	1	2	Tot.
	----- % cover -----								
Summer ground skidding (unburned)	11.2	11.9	23.1	19.8	17.4	37.2	16.2	15.1	31.3
Summer ground skidding (burned)	5.0	11.3	16.3	7.4	14.9	22.3	6.5	13.6	20.1
Winter ground skidding (unburned)	16.1	13.8	29.9	14.2	17.4	31.6	14.7	16.5	31.2
Winter ground skidding (burned)	5.3	15.8	21.1	6.0	14.7	20.7	5.8	14.9	20.7
Summer high-lead (unburned)	5.1	23.2	28.3	18.6	25.6	44.2	17.4	25.4	42.8
Summer high-lead (burned)	2.2	11.0	13.2	3.1	8.5	11.6	3.0	8.9	11.9
Winter high-lead (unburned)	22.2	5.6	27.8	28.8	21.2	50.0	27.7	18.6	46.3
Summer grapple (unburned)	7.4	3.7	11.1	30.3	21.4	51.7	24.1	16.6	40.7
Winter grapple (unburned)	25.8	16.1	41.9	48.6	13.5	62.1	43.7	14.1	57.8
Summer jammer (unburned)	21.0	0.0	21.4	21.0	13.2	34.2	21.0	12.2	33.2
Summer skyline (unburned)	—	—	—	33.1	16.6	49.7	33.1	16.6	49.7
All unburned	11.8	12.3	24.1	21.3	19.3	40.6	23.6	17.3	35.9
All burned	4.8	12.1	16.9	6.0	13.5	19.5	5.7	13.1	18.8
All transects	9.3	12.2	21.5	15.8	17.1	32.9	13.9	15.8	29.7

^a/ Slash less than 5-cm diameter^b/ Slash more than 5-cm diameter

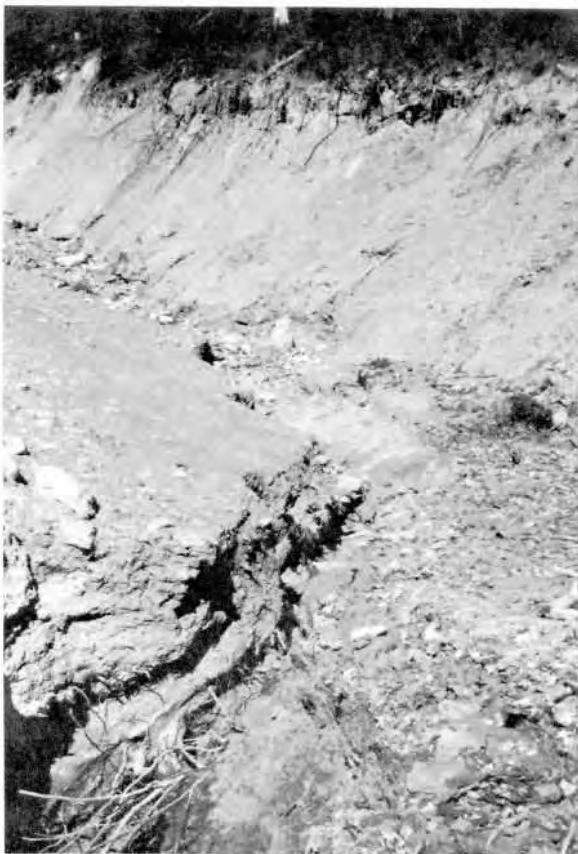


Fig. 27. Channeling in silty roadbed material derived from a soft mudstone.

between roads. In addition, surface soil erosion was prevalent in a few clearcuts which had experienced severe burns (Fig. 16).

The frequent slumping of main road and skidroad cutbanks was to be expected, considering their steepness. It was usually of a small scale, but massive slumping continuing upslope was noted in some seepage-provided soils. Road edge failures were noted fairly commonly. They ranged in magnitude from cracks to major slides.

One clearcut, salvage-logged after a fire, had massive gullying and slides (Fig. 29). The soil was underlain by a bouldery, sandy-clay till, which was compact when dry but tended to move readily when saturated. One steep, extremely unstable medium- to fine-textured soil responded to clearcutting and ground skidding with a series of coalescing slumps and slides (Fig. 30).



Fig. 28. Large gully formed when water was diverted down an existing road. Note the extremely coarse textured nature of the outwash.



Fig. 29. Several massive slides and gullies on a slope salvage-logged after a wildfire.



Fig. 30. Surface erosion and massive slides in very unstable medium- to fine-textured soil on a steep slope. The skid-roads and haul roads are barely distinguishable.

DISCUSSION AND CONCLUSIONS

Mineral soil exposure has been used as the main criterion for soil disturbance; however, it is not necessarily an unfavorable result of harvesting. Establishment of seedlings of tree species such as Engelmann spruce and black cottonwood, are favored by the removal of surface organic horizons, and growth may be enhanced by higher soil temperatures associated with mineral soil exposure (4). On the other hand, mineral soil exposure potentially leads to erosion and stream sedimentation, particularly on the steep slopes under investigation. Furthermore, the depth of gouges and deposits associated with road construction is often greater than what would be optimum for establishment and good growth of seedlings (18). Coupled with the problem of depth are those of instability of cutbanks and sidecast and compaction on roadbeds. The latter can limit the establishment and growth of trees, especially on fine-textured soils (17). Until further specific information is gained, we are assuming that any mineral soil exposure results in an increase in erodibility and that disturbance in the form of gouges and deposits over 25 cm in depth (very deep classification) is potentially harmful to the site.

With the foregoing points in mind, the survey has

demonstrated that a considerable proportion of the steep clearcuts in the Nelson Forest District are excessively disturbed during road construction and logging operations. There is, therefore, justification for the consideration of stricter logging guidelines and the institution of better logging practices in the District. However, the degree of disturbance varies greatly with yarding method, snow conditions at the time of logging and post-logging treatment, particularly prescribed burning, and adjustment of these factors alone will aid greatly in reaching acceptable disturbance levels.

The greatest exposure of mineral soil (about 45% of the clearcut area) occurs with summer ground skidding, mostly from skidroad and haul road construction. This extent of soil disturbance compares with tractor logging on bare ground in other areas as follows: 20.9% in ponderosa pine stands (8), 22% bare ground exposure in pine-fir stands in California (7), 22.2% in Douglas-fir, ponderosa pine, larch stands (19), 35.3% in the western Cascades of Oregon (5) and 69% mineral soil exposure on two clearcuts in Coastal British Columbia (2). On an area salvage-logged after fire in north-central Washington, 36.2% of the clearcut was severely disturbed by tractor logging (9). An additional 37.6% was categorized as slightly disturbed, i.e., very shallow exposure and deposits of mineral soil and mixtures of mineral and organic matter. All the foregoing results were obtained on the ground. Estimates of disturbance from main road, skidroad and landing construction from 1:15,840 scale aerial photographs were lower (18.6 and 14.7%) for two ground skidded clearcuts in the Nelson Forest District (18). Aerial methods would tend to underestimate or even miss some of the shallow disturbance detected by ground surveys.

This survey indicates that soil disturbance could be reduced by almost one-half by ground skidding on snow rather than on bare ground. In addition, the intensity of disturbance is lower when winter logging is used. Klock (9) found an even greater reduction for tractor logging on snow, a method categorized as an "advanced" system for north-central Washington. Faced with a longer snow season, loggers in British Columbia have employed the system widely for many years. Poor utilization (high stumps) during winter logging is a problem under investigation by the Forest Engineering Research Institute of Canada.

High-lead cable systems resulted in about the same order of soil disturbance (road and between road) as ground skidding on snow (17.4% for SHL(u) and

28.6% for SHL(b)). Earlier studies in high-lead clearcuts indicated 15.2% (8), 15.8% (15), 29% (2) and 32% (9) disturbance. The latter three studies did not include haul roads and would therefore have to be compared with the 8.4 and 13.6% non-road disturbance for unburned and burned clearcuts in the present study.

Grapple yarding produced a relatively high amount of road disturbance (22-27%) as a result of the wide tail-hold roads. As there was very low disturbance between roads, total disturbance was in the same order as ground skidding on snow and summer high-lead.

Total disturbance recorded for jammer-yarded clearcuts was 12.7%. Megahan and Kidd (11) noted that jammer yarding could be expected to disturb 25% of clearcuts on steep slopes as a result of road construction alone. This figure seems more reasonable than ours, which was based on a relatively small number of points and on only two clearcuts.

The one skyline clearcut examined had mineral soil exposure of 7.6%, which compares closely with the results for other studies (6, 9, 15, 19). It is the least soil disturbing of all systems surveyed.

Erosion, subsequent stream sedimentation and site deterioration would seem to be much less potential problems of yarding than of road construction. The extent of mineral soil exposed from the yarding operation is small compared with that produced by haul roads and skidroads, i.e., 3.6% versus 41.9% of unburned, summer ground skidded clearcuts. Butt gouging, root overturns and log skinning generally cause fairly discrete patches of mineral soil exposure, which is mainly of a shallow nature. Even on cable-logged areas, the yarding disturbance is only in the order of 10 to 15%. While yarding trails are visible from a distance in the case, for instance, of high-lead settings, close-up inspection did not indicate that a serious erosion potential existed on the clearcuts examined. From the point of view of potential site deterioration and erosion, it is road-related disturbance that must be reduced. Reduction by about one-half can be attained by ground skidding on snow or by using a cable yarding system. In this regard, the grapple-yarder does not attain the same reduction as high-lead, jammer or skyline. It is possible that the density of skidroads used in ground skidding can be reduced by better planning (3) and by modifying techniques, e.g., by using longer mainlines. The major clue found in this study relating to the first



Fig. 31. A 4-year-old summer, ground-skidded clearcut. Note the relatively irregular pattern of skidroads on the more gently sloping area in the middle foreground of the picture.

possibility was that the amount of summer skidroad disturbance was not related to topographic steepness. This reflected a too casual attitude to skidroad planning on the more moderate slopes (30-50%) (Fig. 31). Whether road disturbance from summer ground skidding on steeper slopes could be reduced to the same order as cable methods (less than 20% for high-lead, jammer and skyline) is not known. Reaching this goal will be greatly aided by the handbook on ground skidding procedures prepared for the Nelson Forest District (12). Winter ground skidding does result in road disturbance that is within the same range as obtained with summer cable logging but it has two possible disadvantages, high stumps and lack of scarified spots between roads. It must also be understood that on very steep slopes (over 60%), ground skidding on snow did not reduce soil disturbance relative to logging on bare ground to anywhere near the extent it did on the more gentle (30-60%) slopes.

Up to this point the discussion has considered unburned clearcuts. Burning can increase the amount of disturbance between roads by two to four or more times. This, coupled with an initial reduction of residual vegetation cover to near zero, means increased erosion potential. Because of the great variation in the amount of mineral soil exposed in burned areas, it is impossible to generalize on the relationship of burning to erosion. However, con-

sidering the steep terrain and a certain initial amount of road and yarding disturbance, mineral soil exposure by burning should be kept to a minimum, certainly less than 20% of the clearcut area, and preferably in spots rather than large, contiguous areas. Twenty percent mineral soil exposure would still allow 2,000 one-m² exposed patches per ha. The survey indicates that many burns expose less than this amount of mineral soil, but that some exceed it by several times. Adherence to slash burning guidelines (1, 12, 14) is of great importance.

The rate of revegetation between roads tends to be, on the average, much the same for burned and unburned clearcuts. However, burned clearcuts start with a much lower cover and thus the potential for erosion (product of extent and duration of soil exposure) is higher on burned clearcuts. The capacity of vegetation to recover after burning appears to be related to biogeoclimatic zone - the lowest capacity occurring in the high-elevation, short growing season Engelmann Spruce - Subalpine Fir Zone and its transition to the Interior Western Hemlock Zone, and the highest capacity in the climatically more moderate Douglas-fir Zone. Fires are more common in the latter zone and quite likely plant species here are more adaptable to burnt surfaces. Road surfaces also lag behind unburned surfaces between roads in vegetative cover and, as with burned surfaces, constitute a greater erosion potential.

Any comments on regeneration must be prefaced by a redefinition of the two major types of natural regeneration: new (trees established since logging) and advance (acceptable trees that have survived the logging operation). A higher stocking of new regeneration is generally found on rather than between roads. Little difference in average stocking of new regeneration occurs between burned and unburned surfaces. Discounting zonal differences, 10 to 15 years are needed to reach a satisfactory stocking level (i.e., over 30% of mil-acres stocked) of natural, new regeneration. Two general options remain to obtain higher stocking levels more promptly. Firstly, depend on a combination of new and advance regeneration. In this case, broadcast burning can not be allowed. Secondly, slash burn, but be prepared to plant. Size of clearcut areas has not been mentioned but is, of course, an important consideration, most of those examined being too large for adequate natural seeding of their central portions. As alluded to, there are zonal differences. The Western Hemlock Zone regenerates better after logging than any of the other zones sampled.

One drawback to cable systems in the Interior appears to be a higher slash cover than results from ground skidding systems and the consequently greater need for slash abatement. The survey indicates that slash burning has on occasion been difficult to control on steep slopes, particularly those that have been cable-logged. As mechanical treatment of slash on such steep terrain should not be recommended, either more material will have to be yarded to the landing, the increased fire hazard will have to be accepted, or burning will have to be done under rigidly specified and controlled conditions.

Erosion was recorded as part of the transect measurements and also incidentally beyond the actual transect paths. That recorded on the transects was usually surface wash associated with severe burning, yarding gouges and deposits and road sidecast. This type of erosion is generally shallow in nature. It represents a potential sediment source, but not a serious factor in site deterioration except on extremely shallow soils. Larger-scale erosion events, resulting in gulying and slides, were also recorded, and are recognized as both sediment and productivity problems. They are associated mainly with drainage problems on roads and with particularly erodible soil types. A good discussion of the factors involved in soil erosion in the study area was provided by Utzig and Herring (17, 18).

While details on the extent and degree of disturbance, rate of revegetation, regeneration and erosion following clearcutting have been documented in this and other studies in the Nelson Forest District, there still remain questions on the actual effects on site productivity. Will the same type and degree of disturbance produce a different effect on productivity depending on biogeoclimatic zone or soil type? What is the effect, and is it sufficiently severe to warrant ameliorative action? What rehabilitative measures would be successful? What are the beneficial effects of soil disturbance, and under what conditions do they outweigh the adverse effects? In addition to obtaining answers to these questions, some measurements of changes in stream sedimentation rates and other slope and stream water characteristics after harvesting and burning should be made in the District to better interpret and apply related research from other regions.

MAJOR IMPLICATIONS FOR MANAGEMENT

1. While exposure of mineral soil aids in the establishment of natural regeneration, it also increases the potential for erosion and site deterioration, particularly on the steep slopes under study. Some maximum acceptable extent and severity of soil disturbance will have to be considered. This limit will vary with the site (soil, climate, topography and stand composition), but even on the most stable soils, exposure of mineral soil in excess of 25 to 30% should be avoided on steep slopes. Very deep (over 25 cm) disturbance should be kept to as low a proportion of the total mineral soil exposure as possible.
2. Soil disturbance on clearcuts ground skidded in the summer often exceeds in extent and severity the foregoing suggested maximum limits. Most of this disturbance is related to road (mainly skidroad) construction.
3. Road-related disturbance can be reduced by:
 - a) ground skidding on snow (average soil disturbance one-half that of ground skidding on bare ground).
 - b) using cable yarding systems. Note here that attention should be placed on reducing the disturbance caused by the tail-hold tractor during grapple yarding.
 - c) better planning of summer, ground skidding road systems. Better planning should be particularly effective on moderate slopes, e.g., 30-50%. For steeper slopes, reduction in

road-related disturbance will likely require modified techniques and equipment (e.g., smaller skidders) in addition to improved planning.

4. Reduction of road-related disturbance will have the added benefit of reducing the frequency of major erosional events such as slides and gullying. These events are largely associated with road construction and maintenance.
5. Soil disturbance from logging activities between roads is much less extensive and severe and occurs more in discrete patches than road-related disturbance. It does not appear to be damaging in terms of erosion or site productivity and, in fact, should be beneficial for natural regeneration.
6. Broadcast slash burning reduces slash cover and increases mineral soil exposure, both legitimate management objectives. Some broadcast burns, however, have been overly severe and have resulted in mineral soil exposure well in excess of maximum acceptable limits. Application of broadcast burning on steep slopes requires well defined silvicultural objectives and use of the best available prescribed fire techniques to attain these objectives.
7. The high-elevation Engelmann Spruce - Subalpine Fir Zone and its transition to the Interior Western Hemlock Zone revegetate more slowly after broadcast burning than the Interior Western Hemlock and Douglas-fir Zones. Fire will have to be used cautiously at these higher elevations, particularly where watershed values are a consideration.
8. With the exception of clearcuts in the Interior Western Hemlock Zone, natural regeneration has been generally neither prompt nor adequate. Roads (especially skidroads) provide a better seedbed than undisturbed surfaces between roads, but growth rates need investigation. Better stocking between roads can be attained with smaller clearcuts and preservation of acceptable advance regeneration. Broadcast burning eliminates advance regeneration and, in most cases, must be followed by planting.
9. Unburned, cable-yarded clearcuts were generally left with a greater slash cover than unburned, ground skidded clearcuts. A shift to cable systems will require increased slash abatement programs unless utilization can be improved.

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