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TREE GROWTH ON AND ADJACENT TO CONTOUR SKIDROADS IN THE SUBALPINE ZONE, SOUTHEASTERN BRITISH COLUMBIA

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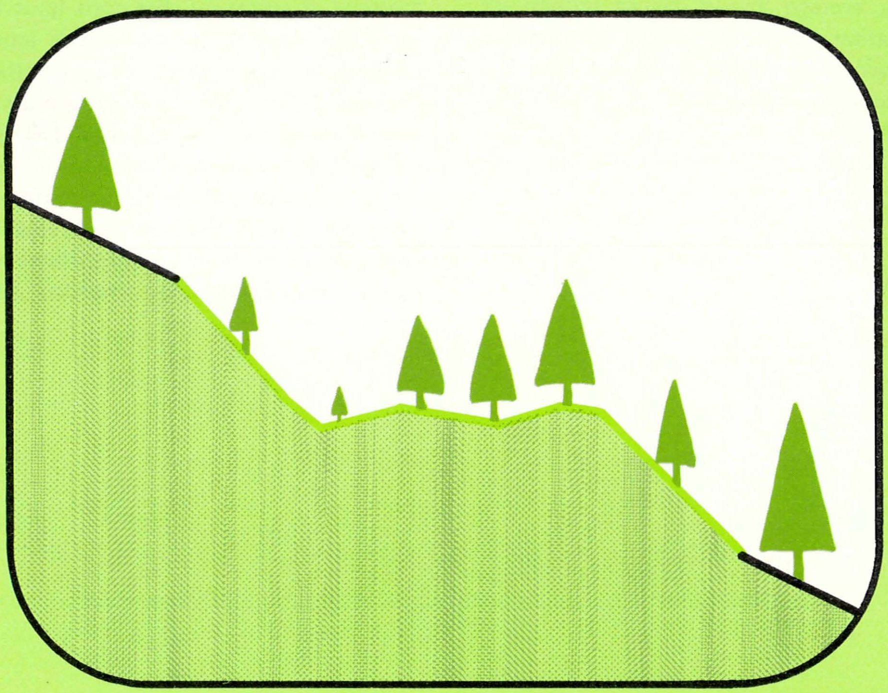

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ABSTRACT

Natural regeneration of Engelmann spruce and subalpine fir in steep clearcuts (9 to 22 years old), established on, above and below contour skidroads, was examined in southeastern British Columbia. Height growth varied with position on skidroad, soil characteristics and aspect. It was generally slowest on the inner deeply gouged portion (cutbank and inner skidder track) of the skidroad and increased toward the outside (outer skidder track, berm and sidecast). On some clearcuts, growth on the outside portion of the skidroad was greater than in the logged but otherwise undisturbed portion. Tree growth was adversely affected on skidroads constructed in medium- to fine-textured soils (loam to silt loam) derived from alkaline parent materials. On these soils, reductions in site quality based on reduced height growth prorated over the whole clearcut were estimated as high as 15% for subalpine fir and 12% for Engelmann spruce. In contrast, disturbance on moderately coarse, acid soils on cool (north) aspects was judged to have beneficial effects on tree growth. In one such area, a prorated enhancement of subalpine fir and Engelmann spruce height growth of 22% and 18%, respectively, was estimated. The post-logging average annual height growth of advance regeneration exceeded that of post-logging regeneration growing on surfaces undisturbed by skidroad construction by 40 to 255%.

RÉSUMÉ

La régénération de l'Epinette d'Engelmann et du Sapin subalpin (âgés de 9 à 22 ans) dans des coupes à blanc sur, au-dessus et au-dessous des chemins de débusquage, a été étudiée dans le sud de la Colombie-Britannique. La croissance en hauteur variait selon la position des arbres sur les chemins de débusquage et selon les caractéristiques et l'aspect du sol. Elle s'est révélée la plus lente sur la partie intérieure fortement creusée (remblai de coupe et trace intérieure de la débusqueuse) du chemin et augmentait vers la partie extérieure (trace extérieure de la débusqueuse, berme et remblai). Dans certaines coupes à blanc, la croissance sur la partie extérieure du chemin de débusquage était meilleure que dans la partie exploitée non autrement détériorée. La croissance des arbres fut amoindrie sur les chemins de débusquage construits dans des sols dérivés de roche-mère alcaline, d'une texture moyenne à fine (loam sablonneux à limon). Sur de tels sols, les réductions de qualité des sites, fondées sur une croissance en hauteur amoindrie au prorata de toute la coupe à blanc, furent estimées jusqu'à 15% pour le Sapin subalpin et jusqu'à 12% pour l'Epinette d'Engelmann. Au contraire, la détérioration sur les sols modérément grossiers et acides du côté nord (plus frais) fut jugée bénéfique pour la croissance des arbres. Dans l'un de ces secteurs on évalua une augmentation proportionnelle de 22% et 18% de la croissance en hauteur du Sapin subalpin et de l'Epinette d'Engelmann respectivement. La croissance annuelle moyenne en hauteur (après exploitation) de la régénération préexistante a dépassé de 40 à 255% celle de la régénération d'après exploitation croissant sur des surfaces non détériorées par la construction de chemins de débusquage.

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INTRODUCTION

More than 95% of the timber cut in southeastern British Columbia (Nelson Forest Region) is harvested with ground-skidding equipment (Wellburn 1975). Much of this occurs on slopes in excess of 50%, which necessitates the use of bulldozers to preconstruct skidroads. Soil disturbance resulting from road construction (including skidroads) averaged about 40% of the area of clearcuts which were ground skidded on bare ground (Smith and Wass 1976), with 8% in haul roads and 32% in skidroads and landings. Haul roads might be considered lost to future wood production but skidroads and landings are generally abandoned and thus available for growing trees. Stocking on these skidroads varies considerably but was found higher on the average than on logged, but otherwise undisturbed, ground (Smith and Wass 1976). This agrees with earlier studies, which have indicated more successful regeneration of conifers on mineral soil than on undisturbed organic matter. In the Engelmann Spruce-Subalpine Fir Zone (Krajina 1969), Engelmann spruce (Picea engelmannii Parry) requires a mineral soil seed bed (Clark, Lerhle and Smith 1954; Dobbs 1972; Griffith 1931; Smith 1955). However, the effect of soil disturbance on its subsequent growth appears to vary from enhancement (McMinn 1974; Smith 1955) to reduction (Herring and McMinn 1978) of growth rates. Differences in findings may, at least in part, be due to differences in the degree of disturbance. Prochnau (1963) and McMinn (1974) found that mixed mineral soil and humus was a better medium for the survival and early growth of white spruce (Picea glauca [Moench] Voss) than pure mineral soil. Concern over the effects of scalping of surface soil horizons led to recommendations on proper windrowing practices (B.C. Forest Service 1976)

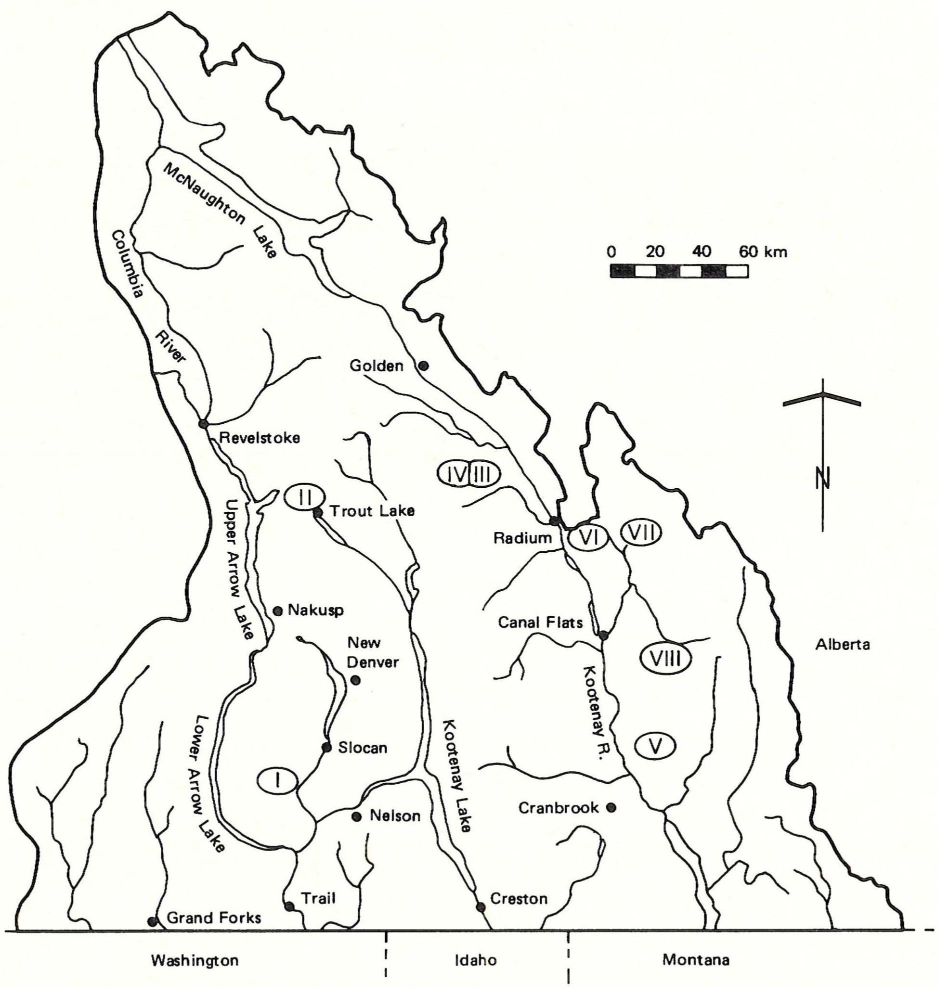


Fig. 1. Map of study area. Circled Roman Numerals refer to drainages sampled: I - Russell Cr; II - Batys Cr; III and IV Templeton Cr; V - Wildhorse Cr; VI - Shuswap Cr; VII - Albert Cr; VIII - Inlet Cr.

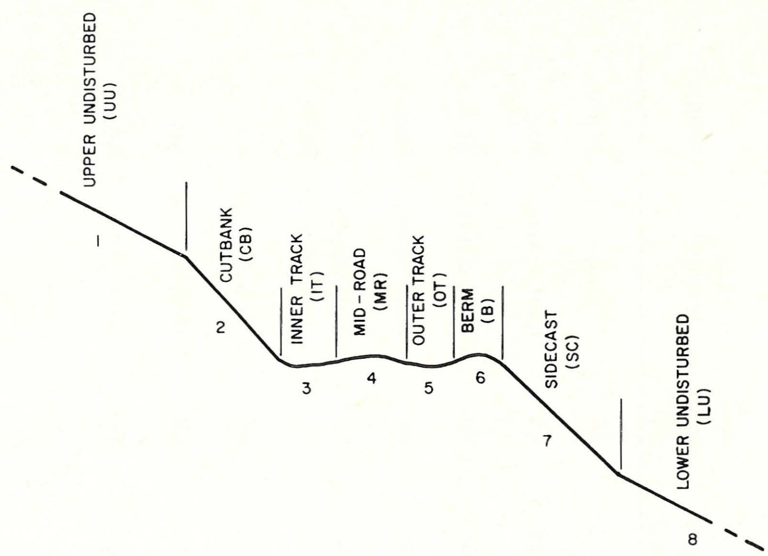


Fig. 2. Skidroad disturbance classification system.

and to investigations of alternatives to blade scarification (McMinn 1974).

Soil disturbance obviously has an effect on tree establishment and juvenile growth that varies with the site and with the type and degree of disturbance. To obtain some quantitative measures of this variation, a study was undertaken to compare the growth rate of trees established since logging on skidroads with trees established on adjacent logged but otherwise undisturbed surfaces.

METHODS

In the summers of 1976 and 1977, clearcuts in the Engelmann Spruce-Subalpine Fir Zone (Fig. 1, Table 1) were selected, with the following characteristics:

- sufficient post-logging (as opposed to advance) regeneration of Engelmann spruce and subalpine fir (Abies lasiocarpa [Hook.] Nutt.) for the sampling system.
- an average slope greater than 45%.
- yarding by ground skidding with wheeled skidders or crawler tractors on bare ground.
- a contour skidroad pattern.
- age from 9 to 22 years.
- a range of aspects.
- a range of soils from coarse textured (gravelly loamy sand) and acid (pH < 5.5) to moderately fine textured (silt-loam), alkaline and strongly calcareous (pH > 7.4).

On each clearcut, contour skidroad sections were selected and a tape laid out 20 to 30 m, depending on density of stocking, along the skidroad. Random numbers were generated to locate points along the tape and at right angles from the tape into the disturbance classes (Fig. 2). The nearest tree of the required species to the point was pulled out of the ground or, if too large, cut off at ground level. Trees older than the age of logging (advance regeneration) were not used, nor were trees younger than one-half the age of logging. This meant that some trees had to be pulled or cut, aged and then discarded. Some slight latitude was allowed in applying the minimum-age rule when no older trees were present in a particular disturbance class. Trees obviously damaged by other than soil disturbance factors, e.g., browsing or rolling logs and windfalls, were not sampled. In 1976 (Areas I, III, IV and VII), two trees per species were sampled from each disturbance class, a total of 16 for each species for each skidroad segment (transect). In 1977 (Areas II, V, VI and VIII), the sampling system was changed and only one tree of each species from each disturbance class (8 per

Table 1. Location, number of trees sampled and general site information for study areas

Area	Age of logging (yr)	No. of transects	No. of trees sampled[a] ES	SF	DF	Avg elev (m)	Avg aspect (deg)	Avg slope (%)	Soil texture[b]	Acidity[c]
I Russell Cr	13-16	21	300	312	0	1626	356	44	Coarse	Strong
II Batys Cr	9	14	72	90	0	1610	192	52	Mod. coarse	Mod.
III Templeton Cr	18	10	160	157	0	1532	356	48	Mod. coarse	Mod.
IV Templeton Cr	19	6	96	93	0	1432	025	52	Mod. coarse	Mod.
V Wildhorse Cr	15	19	135	145	0	1677	292	53	Mod. coarse to medium	Mod.
VI Shuswap Cr	13	11	85	86	0	1644	016	63	Medium	Alk.
VII Albert Cr	22	5	80	0	77	1318	076	48	Medium	Alk.
VIII Inlet Cr	15	20	160	146	0	1549	274	52	Mod. fine	Alk.
			1088	1029	77					

[a] ES = Engelmann spruce
SF = Subalpine fir
DF = Douglas-fir

[b] Mod. = Moderately

[c] Alk. = Alkaline
Mod. = Moderate

transect) was sampled. The number of transects and thus the number of trees sampled in each area varied, depending essentially on the availability of suitable skidroad segments (Table 1).

For each sample tree, total age and height were determined and the previous year's main stem foliage was assessed for color, using the Munsell system. Annual height growth since establishment was measured on a sampling of trees in Areas I, III, IV and VII and on all trees from the other areas by using girdles (bud scale scars) as external indicators of annual growth segments.

Engelmann spruce and subalpine fir were the test species; however, in Area VII, Douglas-fir (Pseudotsuga menziesii [Mirb.] Franco) was more prevalent than subalpine fir and was therefore selected in its place.

In addition to the survey of regeneration established since logging, measurements were made of post-logging height growth of advance regeneration established on the upper and lower undisturbed surfaces. Trees were selected, using the same random sampling technique described earlier, with the proviso that only trees 1.37 m or less in height at the time of logging could be used.

Soil pits were dug in each clearcut, the profiles described and classified (Canada Soil Survey Committee 1978, National Soil Survey Committee of Canada 1974) and soil samples were taken for the following determinations:

1. pH - potentiometrically in a water-soil solution (McMullan 1971).
2. organic carbon - dry combustion (McKeague 1976).
3. carbonate - a) presence - dilute HCl (McMullan 1972).
   b) amount - sulphurous acid treatment plus dry combustion (McMullan 1972).
4. color - Munsell Soil Colors.
5. texture - hydrometer (McKeague 1976).

Plant cover was described by listing species on surfaces undisturbed by skidroad construction. Plant nomenclature follows Hitchcock et al. (1955-69).

Student-Newman-Keuls' multiple range tests (Newman 1939) were performed on data from the 8 disturbance classes for comparisons of tree age and tree height. Additionally, two logical 4-class groupings were tested using total tree height. The first of these combined inner plus outer track (mechanically compacted), mid-road plus berm (level, not mechanically compacted), cutbank plus sidecast, (unstable [sloping], uncompacted) and the upper plus lower undisturbed portions. The second was a simple grouping from the inside to the outside of the skidroad: cutbank plus inner track, mid-road plus outer track, berm plus sidecast and the upper plus lower undisturbed portions. This second grouping was used in the construction of growth curves derived from annual height increments and a subsequent appraisal of changes in site quality resulting from skidroad construction. Curves were constructed on the basis of an exponential function ($Y[\text{height}] = (X[\text{age}]+1)^{e}-1$) and differences tested after logarithmic transformation by analysis of variance.

RESULTS

I. GENERAL DESCRIPTION OF STUDY AREAS

Table 1 lists the study areas in general order from the most coarse and acid (Area I - Orthic Humo-Ferric Podzol developed in coarse colluvium over porphyritic granite bedrock; pH of C, 4.6-4.7) to the finest and most basic (Area VIII - Orthic Eutric Brunisol developed in alkaline, calcareous till over argillaceous limestone, shale and quartzite bedrock; pH of C, 7.8-8.1). Brief profile descriptions, some physical and chemical characteristics and major vegetation are listed in Appendix I. Vegetation on the more acid soils was dominated by Vaccinium membranaceum Dougl., Rhododendron albiflorum Hook. and Menziesia ferruginea Smith, while that on alkaline soils was dominated by Rubus parviflorus Nutt., Acer glabrum Torr., and Salix L. spp. Except where Alnus sinuata (Regel) Rydb. was common (Areas IV and V and some transects of Areas V and VIII), vegetation cover on the roads was generally less than in the undisturbed portions of the clearcuts.

II. POST-LOGGING REGENERATION

Total Height of Trees

1. Eight-class grouping

Three patterns, arbitrarily designated A, B and C, emerged for average total height of trees (Figs. 3

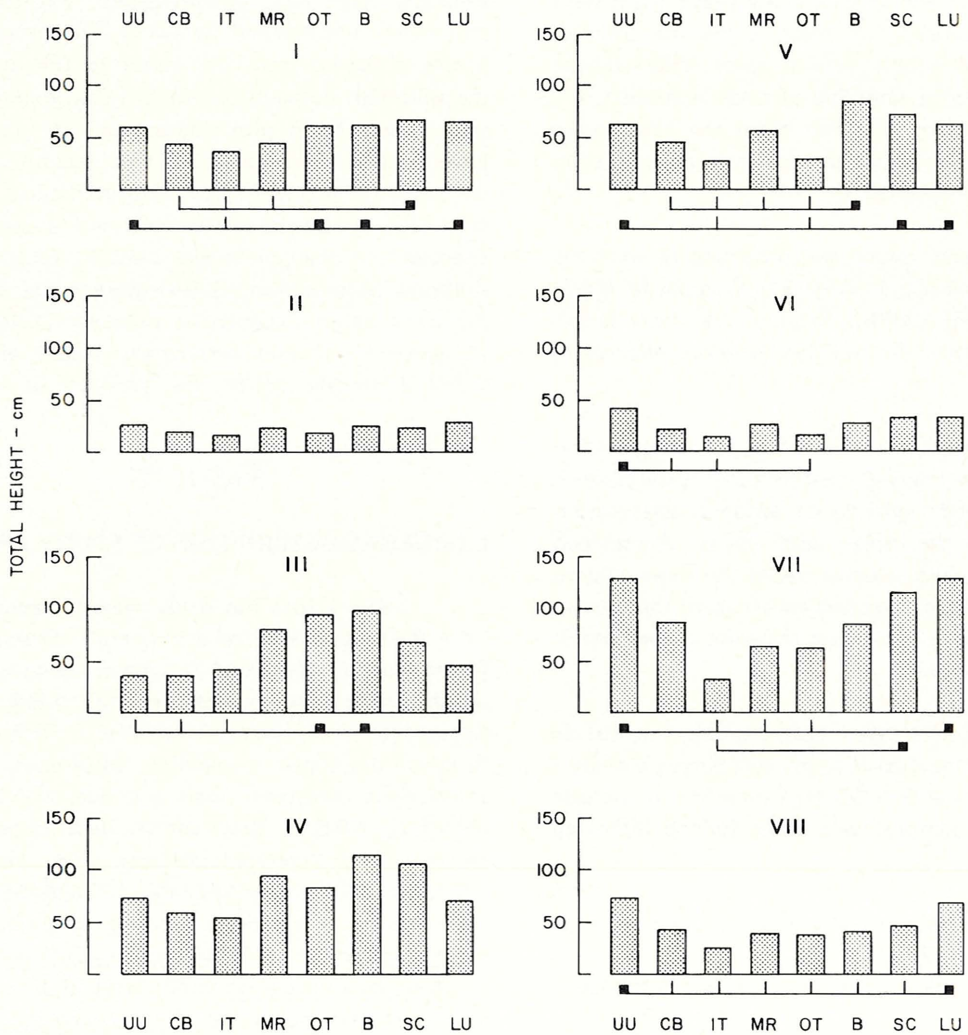


Fig. 3. Bar graphs representing average total heights of Engelmann spruce for each area and disturbance class. Heights with solid squares below the bars are significantly greater (5% level) than those with short vertical marks joined by the same horizontal line. UU = Upper undisturbed; CB = Cutbank; IT = Inner track; MR = Mid-road; OT = Outer track; B = Berm; SC = Sidecast; LU = Lower undisturbed.

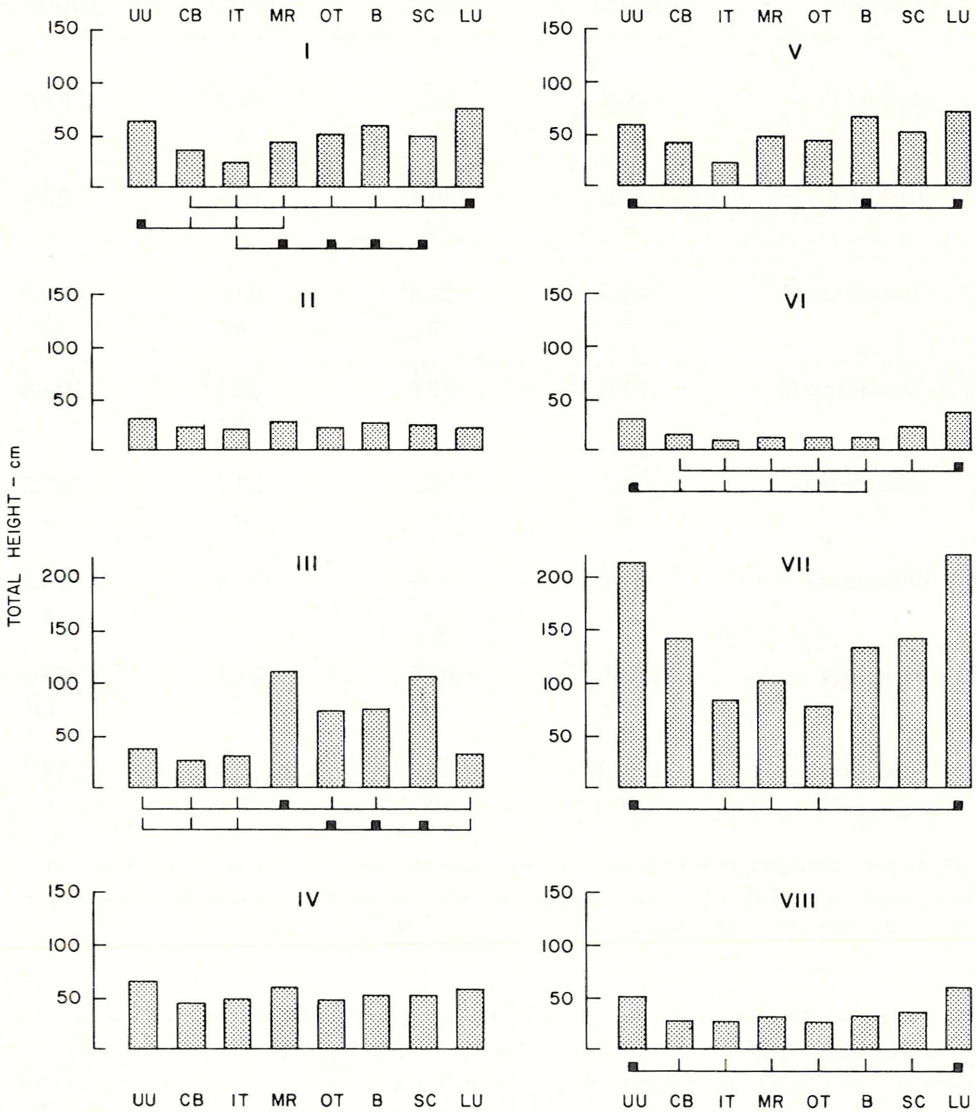


Fig. 4. Bar graphs representing average total heights of subalpine fir (Douglas-fir for Area VII) for each area and disturbance class. Heights with solid squares below the bars are significantly greater (5% level) than those with short vertical marks joined by the same horizontal line. UU = Upper undisturbed; CB = Cutbank; IT = Inner track; MR = Mid-road; OT = Outer track; B = Berm; SC = Sidecast; LU Lower undisturbed.

Table 2. Multiple range tests[a] for heights of Engelmann spruce based on the slope/compaction 4-class grouping

Area		Disturbance class[b] UU+LU	CB+SC	IT+OT	MR+B
		cm			
I	Russell Cr	62.9 a	55.2 a	49.8 a	54.0 a
II	Batys Cr	27.0 a	20.7 a	17.9 a	24.0 a
III	Templeton Cr	41.2 c	52.4 bc	69.6 ab	89.6 a
IV	Templeton Cr	71.8 a	82.2 a	68.5 a	104.9 a
V	Wildhorse Cr	62.7 a	56.2 a	28.3 b	69.0 a
VI	Shuswap Cr	36.7 a	26.0 a	14.6 b	26.7 a
VII	Albert Cr	128.7 a	99.9 ab	47.1 c	73.9 bc
VIII	Inlet Cr	70.7 a	43.8 b	31.0 b	39.7 b

[a] Within areas, significant differences ($p < .05$) occur between means not followed by a common letter.

[b] UU = Upper undisturbed; LU = Lower undisturbed; CB = Cutbank; SC = Sidecast; IT = Inner track; OT = Outer track; MR = Mid-road, B = Berm.

and 4). In Pattern A (Area III), significantly taller trees occurred on the deposit portion (generally outer track, berm and sidecast) than on the gouge (generally cutbank and inner track) portion or on the two undisturbed classes. In Pattern B (Area I), the gouge portion supported significantly smaller trees than the upper and lower undisturbed classes and the deposit portion, particularly the berm and sidecast. In Pattern C (Areas VI, VII and VIII), significantly taller trees occurred on the undisturbed classes than on most of the gouged and all (Area VIII) or some of the deposit-disturbed portions. Area V was intermediate between Patterns B and C, with particularly poor growth on the skidder tracks. No specific patterns could be discerned for Areas II and IV.

2. Four-class groupings

Statistical differences among classes varied, depending on the particular 4-class grouping used. The slope/compaction grouping emphasized the significantly shorter trees on the two skidder tracks, particularly Engelmann spruce and subalpine fir in Area V and Engelmann spruce in Areas VI and VII (Tables 2, 3). The gouge/deposit grouping emphasized the relatively short trees on the cutbank and inner track and their increasing heights outward toward the sidecast. Most illustrative of this trend was Engelmann spruce and subalpine fir in Areas I and III, Engelmann spruce in Area IV and subalpine fir in Area V (Tables 4, 5).

The differences noted in total tree height reflect two major influences, promptness of stocking (age) and site quality (growth rate). These two components are described separately in the following sections.

Table 3. Multiple range tests[a] for heights of subalpine fir based on the slope/compaction 4-class grouping

Area		UU+LU	CB+SC	IT+OT	MR+B
		Disturbance class[c]			
		cm			
I	Russell Cr	68.9 a	40.9 bc	35.9 c	49.5 b
II	Batys Cr	26.5 a	23.8 a	20.8 a	25.2 a
III	Templeton Cr	33.8 c	65.0 b	51.1 bc	92.7 a
IV	Templeton Cr	61.9 a	46.6 a	46.6 a	55.5 a
V	Wildhorse Cr	63.9 a	44.3 ab	32.8 b	56.4 a
VI	Shuswap Cr	33.3 a	18.3 b	10.0 b	11.4 b
VII	Albert Cr [b]	217.1 a	140.8 b	80.0 b	116.4 b
VIII	Inlet Cr	53.3 a	29.7 b	24.7 b	29.9 b

[a] Within areas, significant differences ($p < .05$) occur between means not followed by a common letter.

[b] Douglas-fir sampled rather than subalpine fir.

[c] UU = Upper undisturbed; LU = Lower undisturbed; CB = Cutbank; SC = Sidecast; IT = Inner track; OT = Outer track; MR = Mid-road; B = Berm.

Age of Trees

In all areas, the age of subalpine fir on undisturbed surfaces was significantly higher than on all skidroad surfaces (Table 6). The differences ranged from 1.3 to 4.9 years. There were no significant differences between average ages of subalpine fir trees on the two undisturbed classes or among trees on the disturbed classes. A similar relationship held for Engelmann spruce in Areas II, III, V and VIII (Table 7). In the other areas, Engelmann spruce trees in the upper and lower undisturbed classes were significantly older than trees on some, but not all, of the disturbed classes. Significant differences ranged from 1.2 to 8.0 years. There were no significant differences between average ages of Engelmann spruce trees on the two undisturbed classes. The ages of Douglas-fir at Albert Creek (Area VII) were significantly higher on the lower undisturbed portion than for all disturbed groupings, whereas the average age of trees on the upper undisturbed was significantly higher only than trees on the sidecast (Table 6). Significant differences ranged from 3.0 to 4.9 years.

Height-growth Rates as a Measure of Site Quality

Height-growth curves were constructed for the gouge/deposit grouping, as this provided the best overall definition of growth differences of the two 4-class groupings. Delay in stocking was ignored,

Table 4. Multiple range tests[a] for heights of Engelmann spruce based on the gouge/deposit 4-class grouping

Area		Disturbance class[b] UU+LU	CB+IT	MR+OT	B+SC
		cm			
I	Russell Cr	62.9 a	41.2 b	52.8 a	64.9 a
II	Batys Cr	27.0 a	18.3 a	21.2 a	24.2 a
III	Templeton Cr	41.2 b	40.2 b	88.0 a	83.4 a
IV	Templeton Cr	71.8 b	55.9 b	89.1 ab	110.6 a
V	Wildhorse Cr	62.7 a	36.8 b	43.9 b	78.5 a
VI	Shuswap Cr	36.7 a	16.8 b	20.6 b	30.1 a
VII	Albert Cr	128.7 a	59.2 b	62.6 b	99.2 a
VIII	Inlet Cr	70.7 a	33.3 b	38.1 b	43.1 b

[a] Within areas, significant differences ($p < .05$) occur between means not followed by a common letter.

[b] UU = Upper undisturbed; LU = Lower undisturbed; CB = Cutbank; SC = Sidecast; IT = Inner track; OT = Outer track; MR = Mid-road; B = Berm.

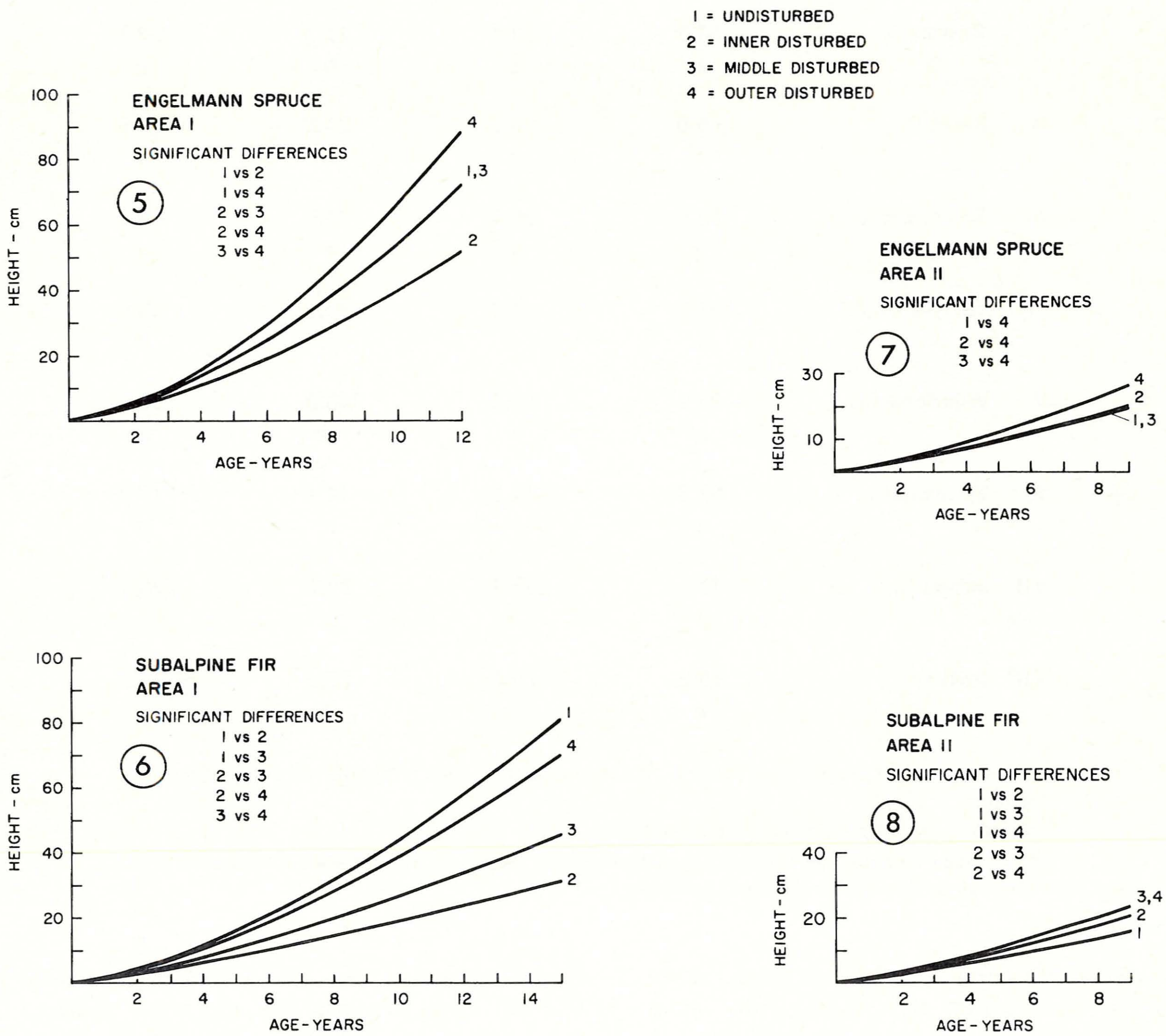
the curves being essentially representative of site quality. All curves were derived from exponential equations.

Considering only those differences between curves significant at $p < .05$, estimates of site quality losses and gains resulting from skidroad construction were made, using growth rates on the undisturbed class as the standard (Table 9). Additionally, using 32.3 as the average percentage of summer ground-skidded clearcuts made up of skidroads and landings (Smith and Wass 1976) and measurements of the widths of the disturbance classes on skidroads in this study, equivalent clearcut areas were computed for each disturbance class (Table 8). Prorated site quality reductions and enhancements were then calculated for each tree species and area (Table 9).

1. Area I (Russell Cr)

Engelmann spruce showed a classic response to skidroad disturbance (Fig. 5). Trees on the gouged inner portion exhibited significantly reduced growth and those on the outer deposit portion significantly increased growth potential when compared with trees growing on the undisturbed surface. The mid-road portion was intermediate in growth potential and not significantly different from the undisturbed. The prorated effect indicated that the better growth on the outside portion of the skidroad cancelled the adverse effects of the gouge when comparisons were made at age 12 (Table 9).

Subalpine fir was more adversely affected than Engelmann spruce, in that trees on both the



Figs. 5 to 8. Height/age curves derived from measurement of annual growth segments for Areas I and II.

Table 5. Multiple range tests[a] for heights of subalpine fir based on the gouge/deposit 4-class grouping

	Area	Disturbance class[c] UU+LU	CB+IT	MR+OT	B+SC
		cm			
I	Russell Cr	68.9 a	28.8 c	45.3 b	53.1 b
II	Batys Cr	26.5 a	20.8 a	24.6 a	24.5 a
III	Templeton Cr	33.8 b	28.1 b	91.0 a	89.5 a
IV	Templeton Cr	61.9 a	44.9 a	53.6 a	50.8 a
V	Wildhorse Cr	63.9 a	30.6 b	45.0 ab	59.2 a
VI	Shuswap Cr	33.3 a	11.6 b	11.1 b	17.4 b
VII	Albert Cr [b]	217.1 a	112.4 b	89.2 b	138.1 b
VIII	Inlet Cr	53.3 a	25.1 b	27.9 b	31.7 b

[a] Within areas, significant differences ($p < .05$) occur between means not followed by a common letter.

[b] Douglas-fir sampled rather than subalpine fir.

[c] UU = Upper undisturbed; LU = Lower undisturbed; CB = Cutbank; SC = Sidecast; IT = Inner track; OT = Outer track; MR = Mid-road; B = Berm.

inner and middle portion of the road exhibited significantly lower growth rates than on the undisturbed (Fig. 6). Height growth on the latter was greater than on the outer portion of the road, but the difference was not statistically significant. The prorated growth loss for subalpine fir measured at 15 years was almost 10% (Table 9).

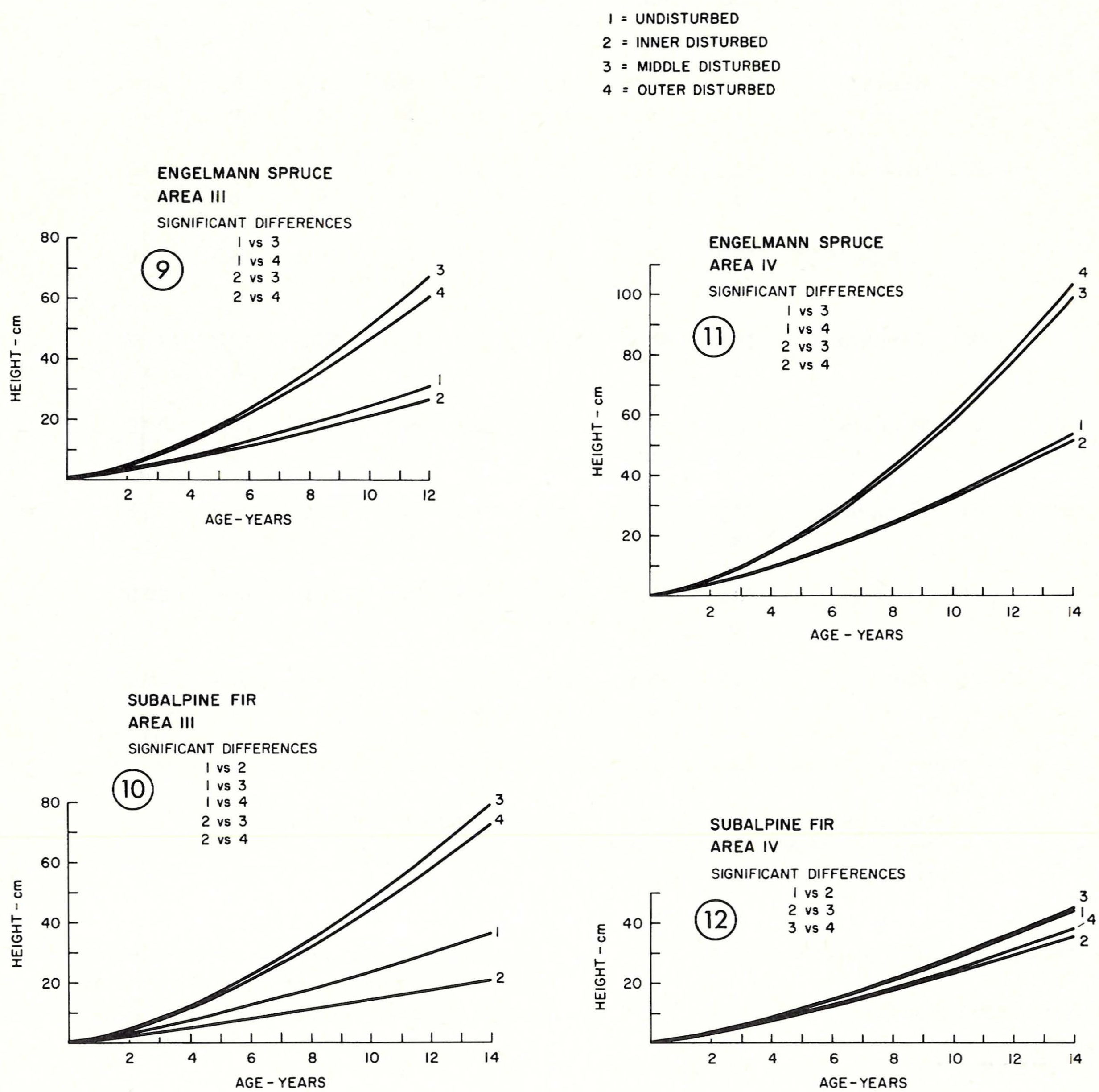
2. Area II (Batys Cr)

Only the outer portion of the skidroad showed a significantly different growth potential for Engelmann spruce (Fig. 7). Here, growth was 34% greater than on the undisturbed at age 9, resulting in a prorated enhancement of 4.7% (Table 9).

Growth of subalpine fir was significantly less in the undisturbed than on all three road surfaces (Fig. 8). When prorated over the whole clearcut, enhancement amounted to 13%.

3. Area III (Templeton Cr)

Gouging, moving and mixing this soil proved beneficial to early growth of Engelmann spruce (Fig. 9) and subalpine fir (Fig. 10). Both species grew at double the rate on the middle and outside portions of the road of those in the undisturbed. For Engelmann spruce, there was no significant difference between growth on the undisturbed and that on the inner skidroad, whereas for subalpine fir, growth on the inner portion was significantly less than in the undisturbed. Prorated enhancement of growth was 22% for Engelmann spruce at age 12



Figs. 9 to 12. Height/age curves derived from measurement of annual growth segments for Areas III and IV.

Table 6. Multiple range tests[a] for ages of subalpine fir on each disturbance class

	Area	UU	CB	IT	MR	OT	B	SC	LU
		Disturbance class[b]							
		years							
I	Russell Cr	11.4 a	10.0 b	9.9 b	9.7 b	9.6 b	9.9 b	9.7 b	11.7 a
II	Batys Cr	10.2 a	7.6 b	7.3 b	7.2 b	7.3 b	7.2 b	8.0 b	10.0 a
III	Templeton Cr	15.1 a	12.8 b	12.6 b	12.8 b	12.1 b	12.6 b	13.5 b	15.0 a
IV	Templeton Cr	16.5 a	12.8 b	12.7 b	13.3 b	13.3 b	13.3 b	12.8 b	17.2 a
V	Wildhorse Cr	13.1 a	10.6 b	10.6 b	10.9 b	10.9 b	11.3 b	10.6 b	13.8 a
VI	Shuswap Cr	10.9 a	7.7 b	7.9 b	7.8 b	8.1 b	7.9 b	8.3 b	9.8 a
VII	Albert Cr[c]	17.9 ab	16.5 bc	16.1 bc	15.3 bc	15.2 bc	15.8 bc	14.6 c	19.5 a
VIII	Inlet Cr	12.8 a	10.4 b	10.5 b	11.3 b	11.5 b	11.2 b	10.5 b	12.9 a

[a] Within areas, significant differences ($p = < .05$) occur between means not followed by a common letter.

[b] UU = Upper undisturbed; CB = Cutbank; IT = Inner track; MR = Mid-road; OT = Outer track; B = Berm; SC = Sidecast; LU = Lower undisturbed.

[c] Douglas-fir sampled rather than subalpine fir.

and 18% for subalpine fir at age 14 (Table 9).

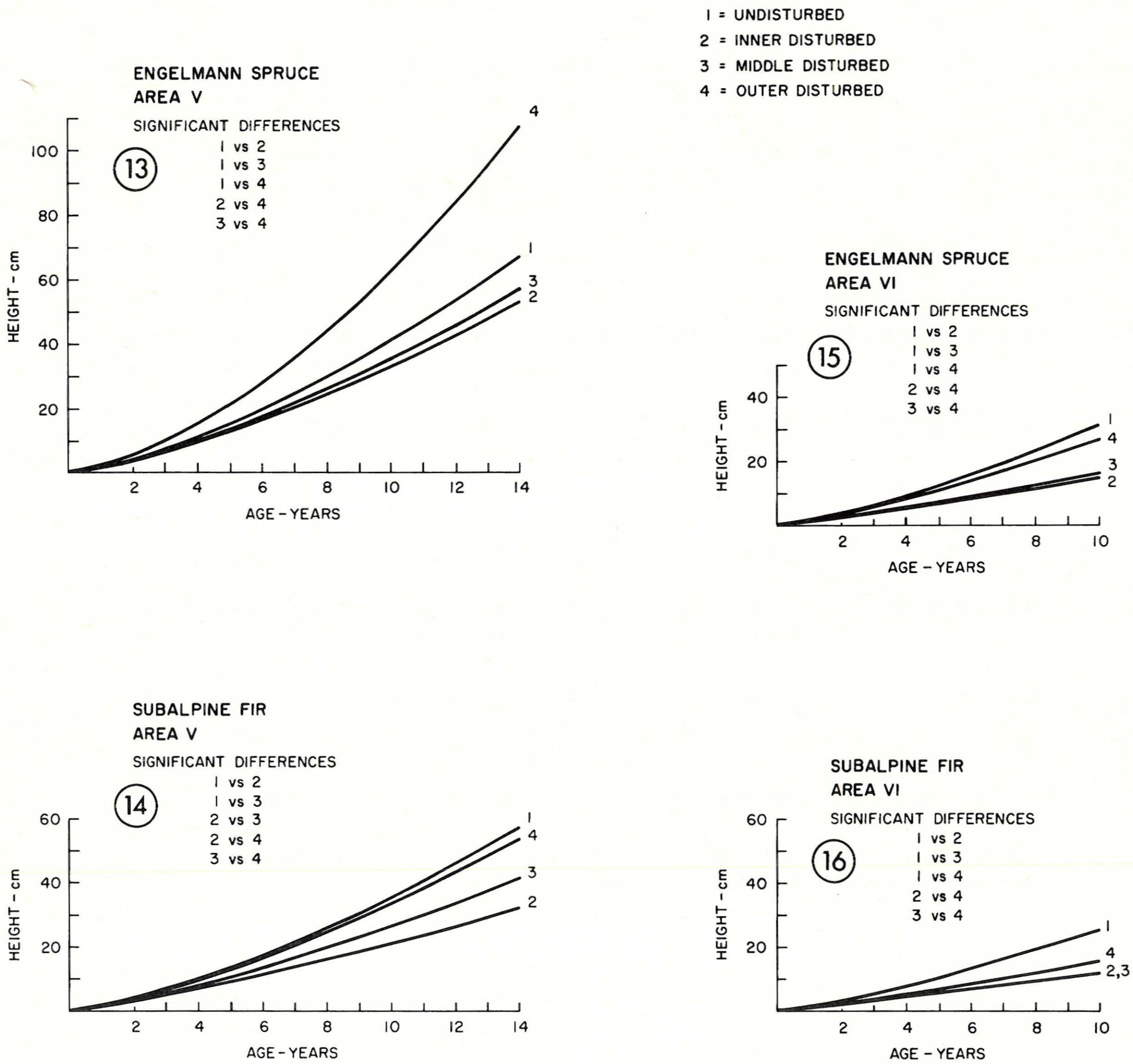
4. Area IV (Templeton Cr)

Engelmann spruce on Area IV responded similarly to Area III, in that growth on the middle and outside portions of the skidroad was significantly greater than in the undisturbed and no difference occurred between growth on the inner portion and in the undisturbed (Fig. 11). The prorated enhancement for Engelmann spruce at age 14 was 19% (Table 9).

Subalpine fir responded differently. No significant differences were found between growth on the undisturbed and that on the middle and outer portions, while growth on the inner portion was significantly less than that on the undisturbed (Fig. 12). The prorated growth reduction amounted to just over 2% at age 14 (Table 9).

5. Area V (Wildhorse Cr)

Engelmann spruce and subalpine fir again showed contrasting growth responses. The former grew significantly slower on the inner and middle portions of the skidroad and significantly faster on the outside portion than on the undisturbed (Fig. 13). The prorated response represented a 5% enhancement at age 14 (Table 9). Subalpine fir also grew significantly slower in the inner and middle portions, but growth on the outer portion was not significantly different from that on the undisturbed (Fig. 14). The prorated growth reduction



Figs. 13 to 16. Height/age curves derived from measurement of annual growth segments for Areas V and VI.

Table 7. Multiple range tests[a] for ages of Engelmann spruce on each disturbance class

	Area	UU	CB	IT	MR	OT	B	SC	LU
		Disturbance class[b] (years)							
I	Russell Cr	11.2 a	10.4 abc	9.9 bc	9.4 c	9.7 bc	9.6 bc	10.0 bc	10.8 ab
II	Batys Cr	8.5 a	6.8 b	6.9 b	6.7 b	7.0 b	6.6 b	6.7 b	10.8 a
III	Templeton Cr	13.6 a	12.2 b	11.8 b	11.8 b	11.8 b	12.4 b	11.8 b	15.1 a
IV	Templeton Cr	16.3 a	13.8 bc	12.2 c	13.8 bc	13.9 bc	13.9 bc	13.2 bc	15.5 ab
V	Wildhorse Cr	12.9 a	10.3 b	8.8 b	9.9 b	9.0 b	10.6 b	10.6 b	12.7 a
VI	Shuswap Cr	10.2 a	7.9 b	8.3 b	9.0 ab	7.8 b	8.2 b	7.7 b	9.4 ab
VII	Albert Cr	19.8 ab	16.7 c	13.1 d	13.4 d	14.4 d	14.8 d	18.0 bc	21.1 a
VIII	Inlet Cr	12.4 a	9.0 b	8.9 b	10.1 b	9.7 b	9.1 b	9.6 b	11.6 a

[a] Within areas, significant differences ($p = < .05$) occur between means not followed by a common letter.

[b] UU = Upper undisturbed; CB = Cutbank; IT = Inner track; MR = Mid-road; OT = Outer track; B = Berm; SC = Sidecast; LU = Lower undisturbed.

was 7% at age 14 (Table 9).

6. Area VI (Shuswap Cr)

There was a significant growth retardation on all three road surfaces for both Engelmann spruce and subalpine fir when compared with growth on the undisturbed surfaces (Figs. 15 and 16). Prorated reductions were 11% for Engelmann spruce and 15% for subalpine fir at age 10 (Table 9).

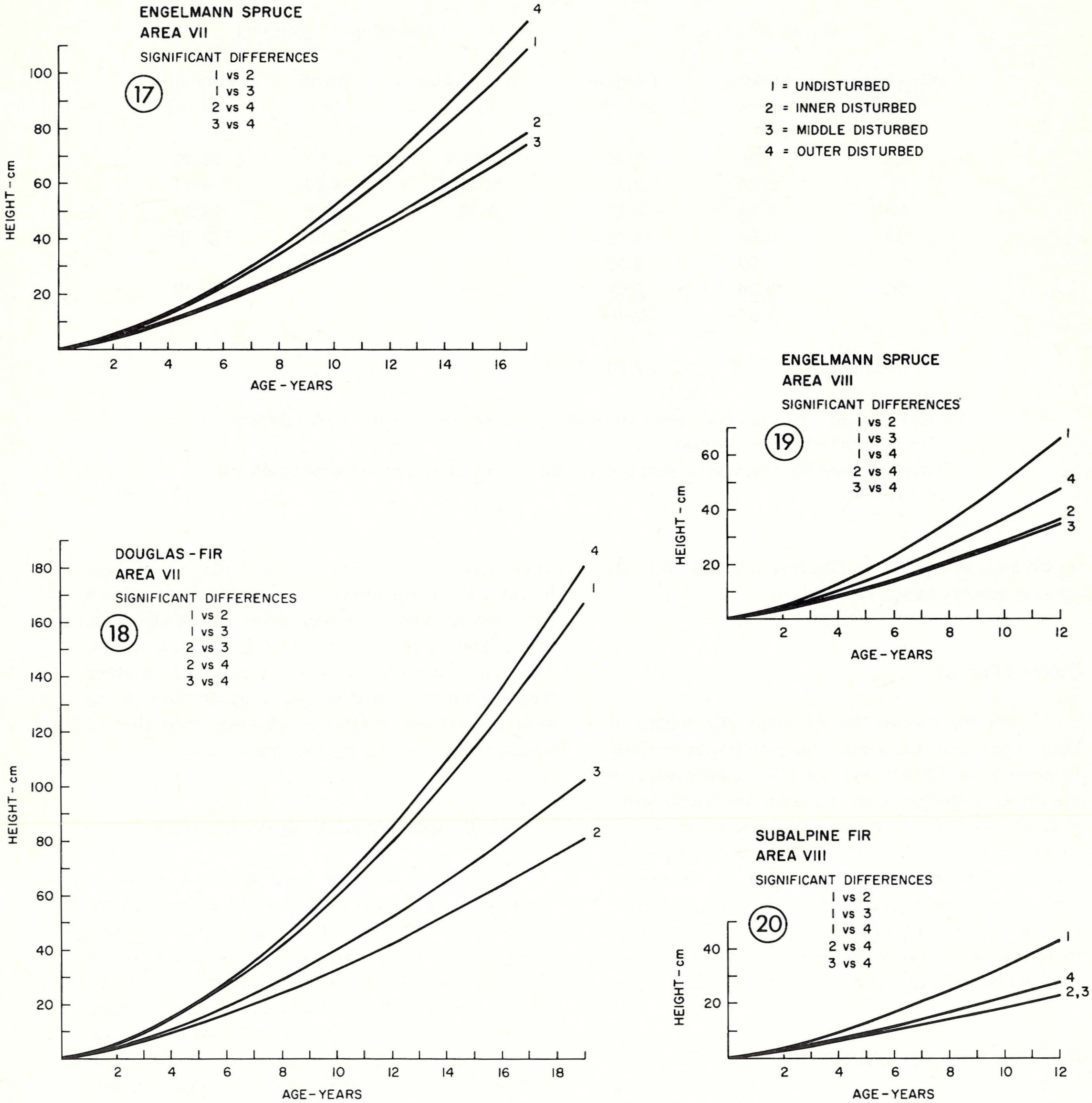
7. Area VII (Albert Cr)

Growth of Engelmann spruce was significantly higher on the undisturbed than on the inner and middle skidroad portions (Fig. 17). No significant differences in rates of height growth occurred between the undisturbed and the outer portion of the skidroad. The prorated reduction for Engelmann spruce amounted to 5% at age 17 (Table 9).

In a similar manner, Douglas-fir height growth was significantly less on the inner and middle skidroad portions, though the differences were greater than for Engelmann spruce (Fig. 18). The prorated growth loss amounted to over 8% at age 19 (Table 9).

8. Area VIII (Inlet Cr)

Both Engelmann spruce and subalpine fir grew significantly slower on all road surfaces than on the undisturbed portion (Figs. 19 and 20). Greatest reduction occurred on the inner and middle portions. Prorated over the whole clearcut, reductions



Figs. 17 to 20. Height/age curves derived from measurement of annual growth segments for Areas VII and VIII.

Table 8. Equivalent percentages of clearcuts for each disturbance class (8-class and gouge/deposit 4-class groupings)

8-class grouping			Gouge/deposit grouping		
Disturbance class[a]	Width (m)	Clearcut area (%)	Disturbance class[a]	Width (m)	Clearcut area (%)
CB	1.62	6.69	CB+IT	2.51	10.40
IT	0.89	3.71	MR+OT	1.94	8.01
MR	1.14	4.72	B+SC	3.36	13.89
OT	0.80	3.29		7.81	32.30[b]
B	1.02	4.20			
SC	2.34	9.69	U+HR		67.70
	7.81	32.30[b]			
U+HR		67.70			

[a] CB = Cutbank; IT = Inner track; MR = Mid-road; OT = Outer track; B = Berm; SC = Sidecast; U = Undisturbed; HR = Haul roads.

[b] Average percentage of summer ground skidded clearcuts in skidroads and landings (Smith and Wass 1976).

would amount to 12% for Engelmann spruce and 13% for subalpine fir at age 12 (Table 9).

Color of Foliage

On the average for all areas, the foliage of both Engelmann spruce and subalpine fir was yellower (average hues 6.3 GY and 5.4 GY, respectively) on the inner disturbed class than on the undisturbed (6.6 GY and 5.8 GY, respectively) and the outer disturbed (6.7 GY and 5.8 GY, respectively). Differences were most marked in Areas I, II and III. No general differences were noted in the average value (lightness of color) or chroma (strength of color), though there was a tendency for lower chromas of foliage on trees on the outer disturbed class of several areas.

III. ADVANCE REGENERATION

In all areas, the average annual height growth since logging for both Engelmann spruce and subalpine fir growing on undisturbed (non-road) surfaces was considerably higher for advance than for post-logging regeneration (Table 10). Engelmann spruce advance regeneration averaged 40 to 157% and subalpine fir 83 to 255% greater height growth than post-logging regeneration of the same species. The advantage of advance regeneration was less marked on coarse acid soils (Areas I to IV) than on finer more alkaline soils (Areas V to VIII), particularly in the case of subalpine fir. Average height growth for released advance regeneration of subalpine fir was greater in all areas than for Engelmann spruce. The height-growth advantage of subalpine fir advance regeneration over post-logging regeneration of the same species was greater in all areas than that of advance over post-logging Engelmann spruce.

DISCUSSION AND CONCLUSIONS

Skidroad surfaces experienced a delay in stocking of conifers compared with adjacent logged, but otherwise undisturbed, surfaces. This delay was at least partly due to the complete removal or burial of seed dispersed from the standing mature trees the autumn preceding logging. Such seed would normally be left intact and available for stocking on the undisturbed portions of the clearcut. In contrast, skidroad surfaces, unless close to an unlogged border, would not receive as much seed as they otherwise would have prior to logging. In addition, skidroad surfaces initially present a harsh environment with respect to seedling establishment, a major limitation being lack of shade (Noble and Alexander 1977). Once other vegetation is established however, the skidroad surfaces, other than those especially compacted or of particularly low fertility, are thought to provide more suitable conditions for seed germination and seedling survival than undisturbed

Table 9. Effects of skidroads on tree height growth on disturbance classes and as prorated over the whole clearcut[a]

Area		Disturbance class[b]	Engelmann spruce Specific enhancement or reduction	Engelmann spruce Prorated enhancement or reduction	Subalpine fir Specific enhancement or reduction	Subalpine fir Prorated enhancement or reduction
			%			
I	Russell Cr	2	−28.1	−2.9	−60.1	−6.2
		3	NS	−	−42.9	−3.4
		4	+23.0	+3.2	NS	−
		T		+0.3		−9.6
II	Batys Cr	2	NS	−	+26.8	+2.8
		3	NS	−	+45.8	+3.7
		4	+33.8	+4.7	+47.6	+6.6
		T		+4.7		+13.1
III	Templeton Cr	2	NS	−	−41.6	−4.3
		3	+112.4	+9.0	+115.3	+9.2
		4	+92.9	+12.9	+97.6	+13.6
		T		+21.9		+18.5
IV	Templeton Cr	2	NS	−	−20.9	−2.2
		3	+82.7	+6.6	NS	−
		4	+89.6	+12.4	NS	−
		T		+19.0		−2.2
V	Wildhorse Cr	2	−20.7	−2.2	−43.0	−4.5
		3	−14.7	−1.2	−27.5	−2.2
		4	+59.2	+8.2	NS	−
		T		+4.8		−6.7
VI	Shuswap Cr	2	−52.0	−5.4	−51.3	−5.3
		3	−46.5	−3.7	−51.3	−4.1
		4	−13.8	−1.9	−38.6	−5.4
		T		−11.0		−14.8
VII	Albert Cr[c]	2	−21.2	−2.2	−51.2	−5.3
		3	−31.6	−2.5	−38.4	−3.1
		4	NS	−	NS	−
		T		−4.7		−8.4
VIII	Inlet Cr	2	−43.8	−4.6	−45.6	−4.7
		3	−46.3	−3.7	−46.0	−3.7
		4	−27.3	−3.8	−34.4	−4.8
		T		−12.1		−13.2

a Enhancements (+) and reductions (−) are calculated based on the maximum tree age for each growth curve and considering growth on the undisturbed to be at a normal rate for the area. NS = No significant differences.

b 2 = Cutbank + inner track; 3 = Mid-road + outer track; 4 = Berm + sidecast.

c Douglas-fir sampled rather than subalpine fir.

Table 10. Comparison of average rates of annual height growth since logging between post-logging and advance regeneration on undisturbed surfaces

		Engelmann spruce			Subalpine fir		
		Regeneration			Regeneration		
	Area	Post-logging	Advance	Difference	Post-logging	Advance	Difference
		cm		%	cm		%
I	Russell Cr	5.67	7.92	40	5.93	10.87	83
II	Batys Cr	3.06	4.31	41	2.61	5.44	108
III	Templeton Cr	2.82	4.87	73	2.22	5.12	131
IV	Templeton Cr	4.39	7.69	75	3.63	9.90	173
V	Wildhorse Cr	4.93	12.69	157	4.83	14.53	201
VI	Shuswap Cr	3.54	7.12	101	3.05	10.01	228
VII	Albert Cr	no advance regeneration					
VIII	Inlet Cr	5.69	13.37	135	4.09	14.52	255

organic surfaces. Reasons for this are increased available moisture (Eis 1965) and decreased maximum temperatures (Noble and Alexander 1977) in the mineral soil. Thus, while stocking on skidroad surfaces is generally delayed when compared with undisturbed surfaces, these disturbed surfaces often eventually attain a higher level of stocking with post-logging regeneration.

Deep gouging of soil during construction generally reduces the growth of trees that become established on the inside portion of the skidroad, presumably because of removal of upper, relatively nutrient-rich soil layers and exposure of a relatively sterile and often compact subsoil. Compaction may also be increased through the operation of skidding equipment. In contrast, increased tree growth on the deposit portion of the skidroad may be attributed to a better nutrient status, particularly with regard to nitrogen levels, and the absence of natural compaction, at least to the bottom of the deposit. Bearing in mind that Area III was situated on a steep, high-elevation, north-facing slope where insolation is low (Geiger 1957) and where moisture is not likely a limiting factor, greater growth here on the deposit portions than on adjacent undisturbed surfaces has two suggested causes: higher average growing season temperatures in the skidroad than in the undisturbed soil (Dobbs and McMinn 1973) and less competition from shrubs, advance regeneration and small residual trees on the skidroad than in the undisturbed.

The areas that experienced an overall reduction in growth on the disturbed surface were those with alkaline, calcareous, medium to moderately fine-textured parent materials. The possible adverse effects of calcareous soil on tree growth have been discussed by Utzig and Herring (1975). Exposure of subsoils with reactions in the 8.0 pH range were obviously detrimental to the growth of conifers, particularly subalpine fir. Sampling of such soils on north, east and south aspects showed fairly similar results. On the north aspect, the nature of the soil apparently overrode any advantage gained through soil disturbance relating to increased soil temperatures. The calcareous soils, finer textured than the acid soils, were characterized by lower growth rates in the outer track than in the mid-road, and for subalpine fir, even lower there than in the inner track (Areas VII and VIII). This suggests that compaction by skidding equipment has had an adverse effect on tree growth on these finer textured soils. This agrees with soil mapping interpretations, which have generally placed the moderately fine to fine-textured soils (the clay and silt loams) in the high compaction hazard category (Cotic 1974; Runka 1972). No clay loams or clays were sampled in this study so that the full effects of compaction were not likely encountered. Area V also showed effects of mechanical compaction even though it was a moderately coarse to medium-textured soil. The extremely coarse soil at Area I showed no effects of mechanical compaction, the pattern of growth being dominated by a steady increase in tree height from the cutbank out toward the sidecast.

The calculations of site quality loss or gain are strictly applicable only for the particular period in time that the assessment was made. Arguments could be made for a future amelioration of adverse effects and for a reduction in enhanced growth. Improvement of unsatisfactory soil conditions, e.g., by leaching of free carbonates and by reduction of compaction through plant, animal and frost action, are likely to occur with time. Counterbalancing this trend toward improved growth would be the onset of competition between trees on the usually excessively stocked skidroad surfaces, while trees established between roads gradually release from shrub competition. Because of these projected contrary and unquantified future trends, the decision has been to take the present differences in growth at their face value and to offer them as indicators of the effects of skidroad construction until longer-term data become available.

Using growth of trees on undisturbed surfaces as the basis for comparison may itself be erroneous if the road construction has caused an overall decrease in site productivity. This might occur through loss of seepage water to layers below the rooting zone or redirection of subsurface flow off the site. Examination of such a possibility could only come from a comparison of growth rates on adjacent roaded and non-roaded logged or burned areas, along with careful monitoring of soil moisture, nutrient and temperature regimes.

The comparisons of height growth since logging of advance growth with post-logging regeneration indicate the benefits of protecting good specimens of the former during logging operations. Good specimens may be defined following Herring's (1977) criteria as Class 1 (0.0-1.3 m height at time of logging) and free of serious injuries or bole malformations. There appears to be a particularly great advantage in retaining such advance regeneration on medium- to fine-textured, calcareous soils prevalent in the eastern reaches of the study area, though further observations would be needed to confirm this finding.

MANAGEMENT IMPLICATIONS FOR THE ENGELMANN SPRUCE-SUBALPINE FIR ZONE

1. Deep disturbance, such as that caused by skidroad construction on steep slopes with soils that are either alkaline and medium- to fine-textured or acid and coarse, may cause significant reductions in site quality. Prorated on the basis of a 32% skidroad coverage, reductions in productivity were estimated as high as 15% for subalpine fir and 12% for Engelmann spruce at an age of about 12 years. Reducing skidroad widths and densities on these sites would correspondingly reduce losses in growth potential.

2. On moderately coarse-textured soils with cool (north) aspects, soil disturbance enhanced juvenile tree growth, in addition to contributing to adequate stocking. Despite this, one would not support increased activity of this type because of an increased potential for surface erosion and mass wasting associated with road building. However, the study shows that contour skidroads on these sites do not impair and, in fact, may enhance (up to 22% in this study) site productivity when tree growth between roads is used as the basis of comparison.

3. Because of the relatively good growth of trees on the outside portion of skidroads on acid soils, these situations should be favored over inside portions when planting and during weeding or spacing of overstocked stands. The berm, in particular, provides a stable soil base of an inferred relatively good (non-compacted) structure, and reasonably good nutrient levels because of the mix of topsoil and subsoil. The cutbank and inner track should be avoided as planting sites unless trees are desired on the former to increase soil stability. Because of mechanical compaction, the outer track on medium- to fine-textured soils should also be avoided.

4. The greater height growth since logging of small (less than 1.37 m at time of logging) advance growth compared with post-logging regeneration supports efforts to protect the former during logging operations. Measures for such protection include a reduction of road construction on snow-free ground and winter logging. The values saved through reduced destruction of advance regeneration and less soil disturbance, with a corresponding decrease in associated on- and off-site impacts, should be considered as offsetting to any increased costs associated with a reduced road network.

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Appendix I. Soil and vegetation data for study areas

Area/Terrain description	Major soil horizons[a]	pH	Texture[b]	Soil sub-group	Dominant understory plants[c]
I Russell Cr.	L	–	–	Orthic	Vaccinium membranaceum
Shallow, moderately coarse to	FH	4.4	–	Humo-	Rhododendron albiflorum
very coarse colluvium over	Ae	4.5-4.6	–	Ferric	Sorbus sitchensis
coarse-grained acidic bedrock	Bf1	4.9	gsl	Podzol	Tiarella unifoliata
or compact glacial till.	Bf2	4.6-4.9	gsl		Rubus pedatus
	C	4.6-4.7	gls-vgs		Gymnocarpium dryopteris
					Clintonia uniflora
					Brachythecium sp.
II Batys Cr.	L	–	–	Brunisolic	Vaccinium membranaceum
Shallow, medium to moderately	FH	4.4-4.5	–	Gray	Rhododendron albiflorum
coarse textured colluvium	Ae	–	–	Luvisol	Pachystima myrsinites
over medium-grained bedrock	Bf	4.5-4.7	gsl-gl		Sorbus sitchensis
to moderately deep, moderately	Bm	4.1	gsl		Epilobium angustifolium
coarse colluvium over basal till.	Bt?	4.9	vgsl		Arnica mollis
	BC	4.3	gl		Polytrichum juniperinum
	C	4.4-4.9	gl-vgsl		
III Templeton Cr.	L	–	–	Podzolic	Menziesia ferruginea
Shallow, moderately coarse	FH	4.4-4.7	–	Gray	Vaccinium membranaceum
textured colluvium over	Ae	4.2-4.6	gsl-gl	Luvisol	Rhododendron albiflorum
medium-grained bedrock to	Bf	4.9	gsl-gls		Cornus canadensis
deeper colluvium over	Bt	4.5	gsil		Pyrola secunda
moderately coarse basal till.	BC	5.1	gls-gsl		Pleurozium schrebiri
	C	5.1-5.2	vgs-vgsl		Polytrichum juniperinum
					Cladonia spp.
IV Templeton Cr.	L	–	–	Podzolic	Menziesia ferruginea
Shallow, moderately coarse	FH	4.3	–	Gray	Vaccinium membranaceum
textured colluvium over	Ae	4.5	l-vfsl	Luvisol	Cornus canadensis
medium-grained bedrock to	Bf	5.1	gsl		Linnaea borealis
deeper colluvium over	Bt	4.5	gl-gcl		Pleurozium schrebiri
moderately coarse basal till.	BC	5.0	vgls		Polytrichum juniperinum
	C	5.5-5.7	vgls-vgsl		Dicranum scoparium
					Cladonia spp.
V Wildhorse Cr.	L	–	–	Mini	Menziesia ferruginea
Gravelly, moderately coarse	FH	–	–	Humo-	Vaccinium membranaceum
textured fluvial fans or	Ae	–	–	Ferric	Alnus crispa
colluvial/morainal blankets	Bhf	4.8-5.9	gsl-gsil	Podzol	Lonicera utahensis
over mainly medium-grained	BC	5.8-6.1	gsil		Rubus parviflorus
bedrock of moderate acidity.	C(Ck)	6.0-8.1	gl-gsl		Tiarella unifoliata
					Streptopus amplexifolius
					Polytrichum juniperinum

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