AREA OCCUPIED BY ROADS, LANDINGS, AND BACKSPAR TRAILS FOR CABLE-YARDING SYSTEMS IN COASTAL BRITISH COLUMBIA: RESULTS OF FIELD SURVEYS

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Abstract

Area occupied by haul roads, landings, and backspar trails was estimated for 156 cutblocks to determine typical site-occupancy values for cable-yarding systems commonly used in Coastal British Columbia. Four categories of yarding systems were compared: grapple, combined grapple/highlead, highlead, and skyline. Site occupancy levels (the proportion of cutblock area occupied by roads, landings, and trails) are presented and discussed for the four systems.

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Disclaimer

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Summary

Information on area occupied by haul roads, landings, and backspar trails (site occupancy) is limited for the cable-yarding systems commonly used in Coastal British Columbia. At the request of the Coastal Timber Harvesting Interpretations Working Subgroup—a joint committee of British Columbia Forest Service and industry representatives—FERIC undertook a survey to address this information gap. The objectives of the survey were:

- Document ranges and averages of haul road, landing, and backspar trail densities for grapple, highlead, and skyline yarding systems.
- Document road dimensions over a range of sideslopes and develop a relationship between slope steepness and road width.
- Estimate and compare site occupancy levels for the various yarding systems.

Six woodlands divisions operating on Vancouver Island, the Queen Charlotte Islands, and the Southern Coast of the mainland provided data on 156 cutblocks. Each cutblock was assigned to one of four yarding-system categories: grapple (90 cutblocks), grapple/highlead (44 cutblocks), highlead (13 cutblocks), or skyline (9 cutblocks). Information on length of haul roads and backspar trails, and number of landings, was collected from 1:5000 maps of each cutblock. A subsample of cutblocks at each woodlands division was then field-checked to verify map information and to measure road, landing, and backspar-trail dimensions.

Grapple-yarded cutblocks contained significantly more haul road and backspar trail per hectare (52.1 and 39.7 m/ha, respectively) than highlead cutblocks (40.7 and 3.3 m/ha), which in turn contained significantly more road than skyline cutblocks (19.1 and 1.3 m/ha). Average densities of haul road and backspar trail for combined grapple/highlead cutblocks (47.6 and 19.8 m/ha) were intermediate of grapple and highlead cutblocks. However, the average number of landings per cutblock was 7.3 for highlead, 6.3 for grapple/highlead, 3.4 for skyline, and 2.3 for grapple cutblocks.

Three hundred and thirty-seven haul-road cross sections were measured on 21 sample cutblocks to investigate relationships between haul-road widths and slope steepness. Total road width, measured from the top of the cutbank to the bottom of the sidecast, increased from an average of 12.6 m on 0-5% slopes to 25.7 m on 76% slopes. Almost all of the increase occurred in the sidecast component; road-surface widths were essentially constant over all slopes, while decreases in ditch widths were offset by increases in cutbank widths as sideslope increased. Although the relationship between road width and slope steepness was statistically significant, slope steepness explained only about 24% of the variance associated with road width.

Slope/width relationships for backspar trails were also investigated by measuring 211 backspar trail cross sections on 12 grapple-yarded cutblocks. Average widths increased—from 4.3 m on 0-5% slopes to only 4.6 m on 56% slopes—but the increase was not significant.

Total site occupancy (percent of cutblock area occupied by roads, landings, and trails) was significantly lower on skyline (4.5%) than on highlead cutblocks (9.3%), which in turn was significantly less than on grapple cutblocks (11.8%). When backspar trails are excluded, there is no significant difference between occupancy levels on grapple and highlead cutblocks (10.0 and 9.0%, respectively). When both backspar trails and areas in sidecast slopes are excluded, site-occupancy levels become 6.5% for grapple, 6.0% for highlead, and 2.9% for skyline cutblocks.

Due to the limited number of samples for highlead and skyline systems, and other sampling limitations with respect to geographic distribution, terrain difficulty, slope, and cutblock area, site-occupancy levels presented here should be regarded only as estimates. *It is further stressed that site occupancy as defined in this report is not equivalent to site degradation as defined by the Vancouver Region of the British Columbia Ministry of Forests.*

INTRODUCTION

In Coastal British Columbia, pressures on the existing forest land base are high and future withdrawals of forest land for non-industrial uses are likely. To minimize the impact of these withdrawals on wood-harvesting levels, the Coastal forestry community must develop strategies to maintain the productive capability of the land that remains available for timber production. A component of these strategies must ensure that the amount of productive forest land dedicated to a network of permanent roads, trails, and landings for harvesting, silviculture, and protection activities is minimized.

However, information needed to achieve this goal is not readily available. A literature review commissioned by the Coastal Timber Harvesting Interpretations Working Subgroup and conducted by the Forest Engineering Research Institute of Canada (FERIC) concluded that information available about site-occupancy levels (i.e. proportion of total cutblock area occupied by roads, trails, and landings) was insufficient for the cable-yarding systems commonly used on the Coast (Rasmussen 1991). Rasmussen recommended further study of relationships between harvesting systems, slope steepness, and road-occupancy levels. At the Subgroup's request, FERIC surveyed representative Coastal harvesting operations to document and compile information on the proportion of cutblock area typically affected by the construction of haul roads, landings, and backspar trails. This report summarizes the findings of the survey.

It is stressed that the purpose of this report is to describe and compare, in general terms, how the common cable-yarding systems are currently being applied in Coastal British Columbia with respect to their road, trail, and landing requirements. *Site-occupancy levels presented here are not equivalent to site degradation as defined by the Vancouver Region of the British Columbia Ministry of Forests* (BCMOF 1990, 1991).

The Regional Soil Conservation Committee (a joint committee of Forest Service and industry representatives) is currently refining working definitions of site degradation. Its definition, not the ones in this report, must be applied when calculating site degradation levels for inclusion in Pre-Harvest Silviculture Prescriptions in the Vancouver Region.

OBJECTIVES

The purpose of this survey was to obtain data on road, landing, and backspar trail occupancy associated with cable-yarding systems used in Coastal British Columbia. This report:

- Describes and compares ranges and averages of haul road, landing, and backspar trail densities for cutblocks harvested with grapple, highlead, and/or skyline systems.
- Documents road dimensions over a range of sideslopes and develops a relationship between slope steepness and road width.
- Using the above information, estimates and compares the proportion of cutblock area occupied by haul roads, landings, and backspar trails for the different yarding systems.

STUDY METHODS

FERIC's study approach consisted of examining cutblock maps (1:5000 scale) to determine and record the lengths of haul road and backspar trails and the number of landings. To estimate areas, the map data were supplemented with field measurements. Data were collected in three phases. First, FERIC visited several Coastal forestry operations to discuss survey requirements and review current Cutting Permit maps with divisional engineering staff. On the basis of these discussions, cutblocks (or groups of contiguous cutblocks) that met the survey criteria were identified. Finally, sample cutblocks were randomly selected from the population of candidate cutblocks. To ensure each co-operating company's operating conditions and methods were adequately represented, between 60 and 90% of each division's suitable cutblocks were included in the sample for that division.

The sample for each division had to include examples of the principal cable-yarding methods employed by that division. Candidate cutblocks for the survey had to be on Crown land, and had to have been cable yarded within the last three years. (In some instances, cutblocks that were being harvested at the time of the survey, or were scheduled for imminent harvest, were also included.) Cutblocks harvested using two or more types of cable systems (e.g., grapple and highlead) were also acceptable. Cutblocks were excluded if the total area developed by a road section or system could not be determined (e.g., some half settings) or if cable yarding was a secondary harvesting system (e.g., hoe-forwarded settings).

Photocopies of 1:5000-scale topographic maps were obtained for each selected cutblock. In consultation with divisional staff, cutblock boundaries and constructed roads, spurs, landings, and backspar trails were verified and marked on the maps. For those cutblocks with two or more yarding systems, internal boundaries were also identified. Cutblock areas, timber volumes, and other operational details were also recorded.

In the second phase, approximately half of the selected cutblocks within each division were field-inspected by FERIC to check for completeness of the maps, but no attempt was made to verify the lengths of roads and backspar trails.

In the third phase, data on haul road, backspar trail, and landing dimensions were collected from a randomly selected subsample of the field-checked blocks. Widths of haul roads and backspar trails were determined by measuring cross sections at fixed intervals from arbitrarily located starting points. Cross section locations within ten metres of road or trail junctions were excluded. Horizontal and vertical dimensions of cuts, ditches, running surfaces, shoulders, and sidecast slopes were measured and recorded to the nearest 0.1 m at each cross section (Figure 1). Road or trail gradients, sideslopes, soil type and depth, and presence of rock were also recorded. Landing areas were measured by either cross sectioning, if landings were regular in shape, or by surveying around the outer and inner perimeters if they were irregular in shape.

Cutblock maps were digitized to determine block areas, road and backspar trail lengths, and number of landings. This information was then combined with the cross section surveys to calculate occupancy levels for haul roads, backspar trails, and landings.

The following statistical methods were employed to analyse survey data (Bethea et al 1985; SAS Institute Inc. 1988; Steel and Torrie 1980; Walpole and Myers 1978):

- ***Analysis of Covariance*** to test for interactions between cutblock size and haul road densities, and cutblock size and backspar trail densities.
- ***One-Way Analysis of Variance*** to compare haul road, landing, and backspar trail densities by yarding system.
- ***One-Way Analysis of Variance,*** using arcsine transformation, to compare the cumulative percentage of cutblock area occupied by haul roads, landings, and backspar trails; and haul roads and landings only.
- ***Duncan's Multiple-Range Test*** to compare treatment means where ANOVA indicated statistical significance.
- ***Simple Linear Regression*** to determine relationships between average sideslope and haul road, and average sideslope and backspar trail width.

Analysis of Variance and Duncan's Multiple-Range Tests were performed at a 95% confidence level.

BACKGROUND

Scope of the Survey

Three woodlands divisions on Vancouver Island and one on the mainland South Coast were visited between June and August of 1991 to collect maps and field meas-

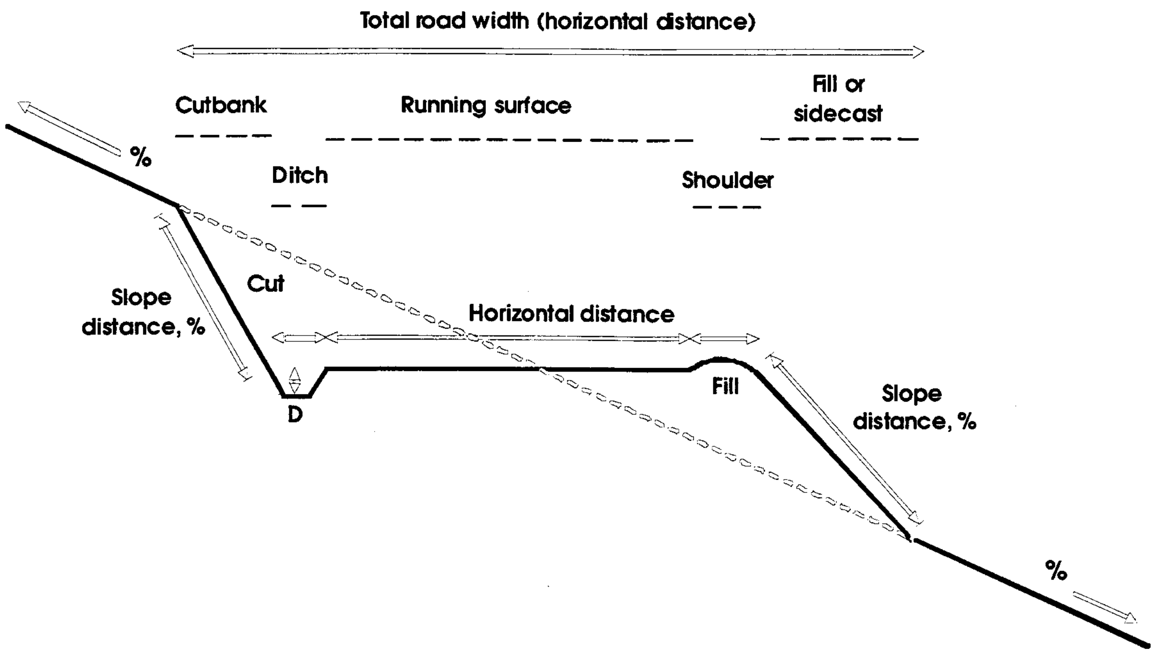

Figure 1. Definitions of road cross sections and measurements.

urements on roads, landings, and backspar trails. Cutblock maps were obtained from another harvesting operation on Vancouver Island, and one on the Queen Charlotte Islands in the fall of 1991, but no field surveys were done on these areas at that time. Available map and field data were summarized into a preliminary report, which was distributed to the Coastal Timber Harvesting Interpretations Working Subgroup and industrial cooperators in January 1992. Discussions with the cooperating divisions and a review meeting with the Subgroup took place in February 1992.

In March, FERIC revisited the cooperating divisions on Vancouver Island and the South Coast to discuss the preliminary report in detail and verify map information where necessary. Some additional sample cutblocks were collected and more roads, landings, and backspar trails were surveyed. Field inspections and surveys were extended to include all except the Queen Charlotte Islands cooperators. At the conclusion of the second phase of field work, about two-thirds of the cutblocks used in this survey had been field-checked. This report includes all the data collected in 1991 and the additional data from the revisits in March 1992.

Distribution of Samples

Distribution by Region. The six logging divisions provided 156 cutblocks for this survey (Table 1).

Cutblocks on Eastern Vancouver Island constitute almost two-thirds of this sample, as this was the first region to be surveyed. Therefore the results are skewed toward relatively favourable development and harvesting conditions. Additional sampling on difficult terrain is recommended to ensure that this part of the spectrum is adequately represented.

Distribution by Yarding System. For the purposes of this survey, cutblocks yarded by grapple or highlead systems were assigned to one of three categories (grapple, highlead, or grapple/highlead) on the basis of the proportion of cutblock area harvested by each system. If 75% or more of the total area was harvested with one system, the cutblock was assigned to that system (i.e., either grapple or highlead). If the primary system accounted for less than 75% by area, the cutblock was grouped into the grapple/highlead category. Although the choice of a 75% limit was somewhat arbitrary, it was felt that beyond this level road and cutblock layout would be governed to a significant degree by the characteristics and capabilities of the primary system. Because sample size was small, it was impractical to differentiate blocks yarded by a skyline system on the same basis. Instead, any block containing more than 50% skyline yarding by area was considered a skyline cutblock.

Table 2 summarizes the distribution of sample cutblocks by yarding system, based on these criteria. Almost 60% of the cutblocks (90 of 156) were grapple yarded. Mixed grapple/highlead areas formed the next largest sample group of cutblocks (44), followed by highlead (13), and skyline (9). The sample sizes for skyline and highlead systems are marginal for statistical purposes. Further sampling of these systems is recommended.

It must be stressed that it was not an objective of this survey to define the relative importance of the various harvesting systems currently used in Coastal British Columbia. The sampling frequencies by yarding systems shown in Table 2 do not, therefore, reflect the actual distribution of harvesting activity for the Coast. Because this survey was concerned only with cable-yarding systems, cutblocks harvested primarily by ground-based or aerial systems (skidding or hoe-forwarding, helicopters) were excluded from the sample. Also, right-of-way and hoe-forwarded areas on sample cutblocks were grouped with cable yarding. Among the cable systems, skyline cutblocks were sampled more intensively than grapple or highlead cutblocks.

Table 1. Distribution of Sampled Cutblocks, by Geographic Area

Cooperator	Location	Cutblocks sampled (no.)	Average cutblock area (ha)	Total area (ha)
A	Eastern Vancouver Island	37	58.4	2159.0
B	Eastern Vancouver Island	35	46.4	1624.4
C	Eastern Vancouver Island	27	88.0	2376.1
D	Central Vancouver Island	26	53.5	1391.4
E	Mainland South Coast	27	46.2	1248.4
F	Queen Charlotte Islands	4	124.3	497.2
	Total	156	59.6	9296.5

Table 2. Distribution of Sampled Cutblocks, by Yarding System

Cooperator	Yarding system				
	Grapple (no. cutblocks)	Grapple/highlead (no. cutblocks)	Highlead (no. cutblocks)	Skyline (no. cutblocks)	Total (no. cutblocks)
A	19	9	9	-	37
B	14	17	4	-	35
C	27	-	-	-	27
D	10	8	-	8	26
E	18	9	-	-	27
F	2	1	-	1	4
	90	44	13	9	156
% of total	57.7	28.2	8.3	5.8	

The integration of several harvesting methods and systems on individual cutblocks should be noted. Hoe-forwarding was commonly, although not extensively, applied on grapple-yarded blocks with favourable terrain, for example. Similarly, grapple-yarding and highlead systems were routinely used together in all but one division, and skyline settings usually included areas of grapple and highlead yarding as well.

While this practice has undoubtedly been motivated by efforts to optimize wood-harvesting costs, it also must have some effect on cutblock and access development and ultimately on occupancy levels. The results of this survey will include this effect because a substantial number of the sample cutblocks combined two or more harvesting systems. However, the survey was not designed to address this question so the magnitude of the effect cannot be determined.

Distribution by Cutblock Size. Table 3 summarizes sampled cutblocks by opening size. Cutblocks in the 20-80-ha size classes are well represented, and those in the 0-20 and 80-100-ha classes to a lesser extent. However, very small (less than 10 ha) and very large (more than 100 ha) opening sizes are insufficiently sampled.

While the sampling method did not deliberately exclude small cutblocks, it contained an inherent bias towards large openings because of the requirement to identify the total area developed by a given road section or system. Therefore, in many instances two or more contiguous cutblocks, sometimes harvested several years apart and occasionally under different Cutting Permits, were grouped together to form one sample cutblock. For example, if a road bisected a cutblock and the upper and lower portions had been harvested at different times, they were combined in this analysis. Thus the average cutblock size in this survey overstates current industry practice.

Currently, opening size is a significant forestry issue in British Columbia. Many forest engineers have expressed concern that reducing opening sizes will produce denser road networks, require more landings and backspar trails, and increase the amount of road in active use. This study cannot adequately address this concern because the selection criteria favoured large units. Further sampling of cutblocks less than 40 ha, with particular emphasis on cutblocks less than 20 ha, is recommended. The results of this study should be useful as a baseline for comparison.

RESULTS AND DISCUSSION

Summaries, by Yarding System

Table 4 summarizes cutblock areas, lengths of roads and backspar trails, and numbers of landings (obtained from 1:5000-scale maps) for each yarding system, and compares this information. Results of statistical analyses are summarized for each parameter in Table 4 (under "significance"). Details of statistical tests are presented in Appendix A.

Cutblock Area. On average, grapple-yarded cutblocks were about 8 ha larger than grapple/highlead and highlead cutblocks (63.3 ha vs. 55.4 ha), and about 16 ha larger than skyline cutblocks (63.3 ha vs. 46.9 ha). However, due to the large variation in cutblock area within each yarding system, these differences were not statistically significant.

Covariance analysis revealed no significant relationship between haul-road density and cutblock size in the survey data. As an example, Figure 2 illustrates the distribution of haul-road densities by cutblock size for the 90 grapple-yarded sites.

Haul Roads. In theory, a cable system that is designed

Table 3. Distribution of Sampled Cutblocks, by Area Class

Area class (ha)	Yarding system Grapple (no. cutblocks)	Grapple/highlead (no. cutblocks)	Highlead (no. cutblocks)	Skyline (no. cutblocks)	Total (no. cutblocks)
0.0-19.9	6	3	3	2	14
20.0-39.9	22	11	2	3	38
40.0-59.9	23	15	1	2	41
60.0-79.9	16	7	4	0	27
80.0-99.9	10	5	1	1	17
100.0-119.9	5	2	2	0	9
120.0-139.9	5	1	0	1	7
140.0+	3	0	0	0	3
Total	90	44	13	9	156

Table 4. Averages and Ranges of Selected Parameters for Haul Roads, Landings, and Backspar Trails, by Yarding System

Parameter	Yarding system Grapple	Grapple/Highlead	Highlead	Skyline
Number of samples	90	44	13	9
Cutblock area (ha)				
Average	63.3	55.4	55.4	46.9
Range	9.1-233.5	14.7-139.7	11.2-107.7	13.0-131.9
Significance[1]	a	a	a	a
Haul roads				
Metres of road/ha				
Average	52.1	47.6	40.7	19.1
Range	24.3-90.9	23.1-70.9	23.9-65.4	0.0-45.9
Significance[1]	a	ab	b	c
Landings				
Number per cutblock				
Average	2.3	6.3	7.3	3.4
Range	0-17	1-27	3-19	1-13
Significance[1]	a	b	b	a
Backspar trails				
Metres of trail per hectare (m/ha)				
Average	39.7	19.8	3.3	1.3
Range	0.0-121.4	0.0-58.6	0.0-18.8	0.0-6.7
Significance[1]	a	b	c	c

[1] For a given parameter, means having the same letter are not significantly different at a 95% confidence level.

to work best over short yarding distances will require more road to log a given area than a system that is designed for long yarding distances. With cable-yarding systems, therefore, road densities would normally be expected to be highest for grapple-yarding, intermediate for highlead, and lowest for skyline. The results of this survey are consistent with this theory. On average, haul-road densities were 52.1 m/ha for grapple-yarded areas, 47.6 m/ha for grapple/highlead areas, 40.7 m/ha for highlead-yarded areas, and 19.1 m/ha for skyline-yarded areas. Compared to grapple-yarded areas, therefore, road densities were 9% less for grapple/highlead

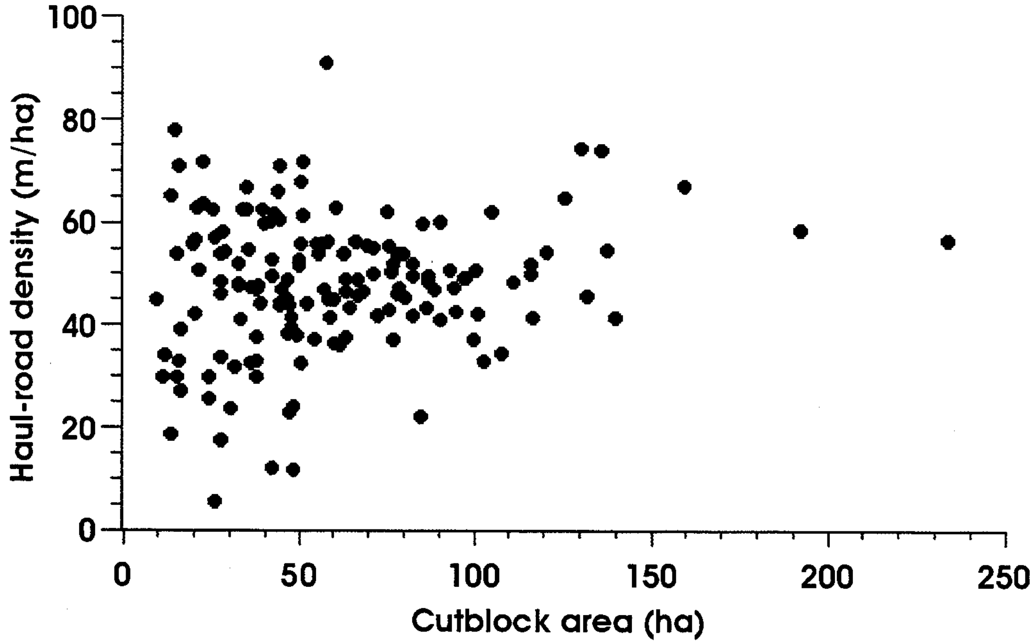

Figure 2. Plot of haul-road density versus cutblock area for grapple-yarded cutblocks.

sites, 22% less for highlead sites, and 63% less for skyline sites.

An alternative way to express haul-road density is in terms of the average area in hectares developed per kilometre of road. For the cutblocks included in this survey, haul roads developed 19.2 ha/km for grapple yarding, 21.0 ha/km for grapple/highlead, 24.6 ha/km for highlead yarding, and 52.4 ha/km for skyline yarding.

The survey results probably overstate the actual difference between grapple yarding and other cable systems today because a significant proportion of the grapple-yarded cutblocks in this survey were harvested with older-model yarders. The current generation of yarding cranes have larger line capacities and faster line speeds, and are therefore more cost-effective at longer yarding distances than older versions. Conversely, average road densities for skyline systems are understated because one cutblock had no haul roads (logs were yarded to an existing road outside the cutblock boundaries), and two cutblocks required only short spurs from previously used roads.

Landings. In terms of average number of landings, grapple and skyline cutblocks had the fewest landings, and grapple/highlead and highlead cutblocks had the most. These differences reflect the greater mobility of grapple yarders, and faster moving and set-up times for highlead yarders than skyline yarders. For example, most cooperators preferred not to build landings on grapple-yarding cutblocks, and built them only where broken terrain or steep slopes made them necessary. Of the 90 grapple-yarded cutblocks surveyed, 42 had no landings. Layout for skyline cutblocks emphasized use of few carefully selected landings, whereas layout for grapple/highlead and highlead cutblocks tended to favour more and smaller landings.

On average, landings on skyline cutblocks developed almost twice as much area as landings on highlead cutblocks (13.6 compared to 7.6 ha/landing). Areas developed per landing could not be estimated for grapple or grapple/highlead cutblocks because of difficulties in distinguishing boundaries between landing and windrow-yarded areas.

The number of landings surveyed was not sufficient to determine whether landing dimension and area differed with yarding system or slope.

Backspar Trails. Because the criteria for classifying cutblocks by yarding system allowed for secondary yarding systems, and mobile backspars were used with grapple yarders wherever possible, some backspar trails were recorded in all yarding system groupings. As would be expected, grapple-yarded cutblocks had the highest average density of backspar trail. Grapple/highlead cutblocks were next highest on average, but individual cutblocks varied considerably depending upon the proportions of grapple and highlead yarding and terrain conditions. Highlead and skyline cutblocks contained only minor amounts of backspar trail.

Dimensions of Haul Roads, Landings, and Backspar Trails

Haul Roads. Three hundred and thirty-seven road cross sections were surveyed over 21 sample cutblocks to examine relationships between haul-road widths and sideslope. Cross sections are well distributed through a range of sideslopes from 0 to 55%. Table 5 and Figure 3 summarize the cross section data by slope class.

Table 5. Average Width of Haul Roads, by Slope Class

		Average width					
Slope class (%)	Samples (no.)	Cut (m)	Ditch (m)	Running surface (m)	Shoulder (m)	Sidecast (m)	Total width (m)
0-5	12	0.1	4.3	5.5	0.3	2.4	12.6
6-15	38	0.9	3.8	5.4	1.3	4.6	16.0
16-25	68	0.9	3.1	5.0	1.7	5.2	15.9
26-35	57	1.3	2.9	5.4	1.8	6.1	17.5
36-45	68	1.8	2.9	5.3	1.7	7.2	18.9
46-55	51	2.7	2.2	5.6	1.8	7.6	19.9
56-65	27	3.9	1.7	5.7	0.7	8.8	20.8
66-75	13	4.5	1.1	5.5	1.1	11.7	23.9
≥76	3	6.0	0.6	7.1	0.0	12.0	25.7
	337						
Weighted average width (m)		1.8	2.8	5.4	1.5	6.5	18.1

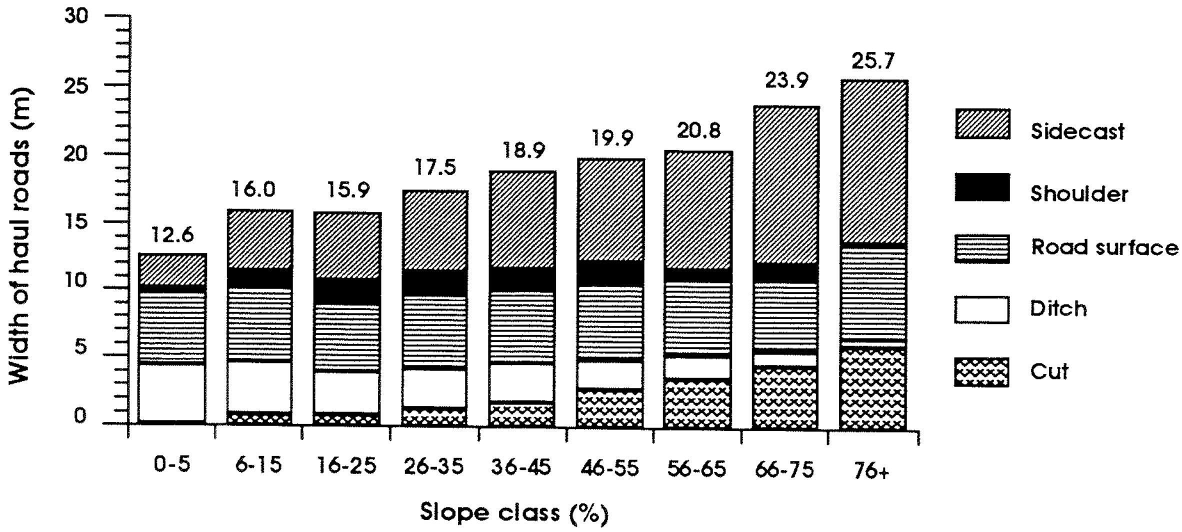

Figure 3. Average width of haul roads, by slope class.

Total road width increases with increasing slope, from 12.6 m on level ground to 25.7 m on 76% slopes. Road-surface widths are relatively constant over the range of slopes surveyed, so the road width/slope steepness trend reflects changes in other components of the road profile.

Cuts increase in width about five-fold from 6-15% to 66-75% slopes, and sidecasts increase about three-fold over the same slope range. In contrast to cuts and sidecasts, average ditch width decreases as slope increases. Wide ditches on gentle slopes were the result of using the ditchline as a source of subgrade and surfacing material, whereas on steeper slopes ditches became narrower due to an increasing rock component in road subgrades.

Regression analysis was applied to investigate the effect of slope steepness on total road width (Figure 4). Best fit was achieved with a linear model with the equation

$$width\ (m) = 13.7 + 0.126 \cdot (\%\ slope).$$

Although this regression is statistically significant, the R^2 value of 0.237 indicates that slope steepness alone explains only about 24% of the variance associated with road width.

Landings. Twenty-one highlead and grapple-yarder landings on 16 cutblocks were surveyed in this study and are summarized in Table 6. The average total area, including cuts and sidecast, was 0.120 ha. On average, the working surface accounted for 45%, sidecast for 30%, and cuts for 25% of total landing area.

The surveyed landings occurred on sideslopes ranging from almost level to 65%. However, the sample size was too small to search for relationships between landing size, slope, and terrain.

For the purposes of this report, the average area of 0.120 ha is used to estimate occupancy levels for landings in the last section, "Occupancy Levels, by Harvesting System".

Backspar Trails. Backspar trails on 12 grapple-yarded cutblocks were sampled to provide information on the relationship of trail dimensions to slope steepness. Two hundred and eleven cross sections were established on slopes ranging from 0 to 65% (Table 7). Most of the

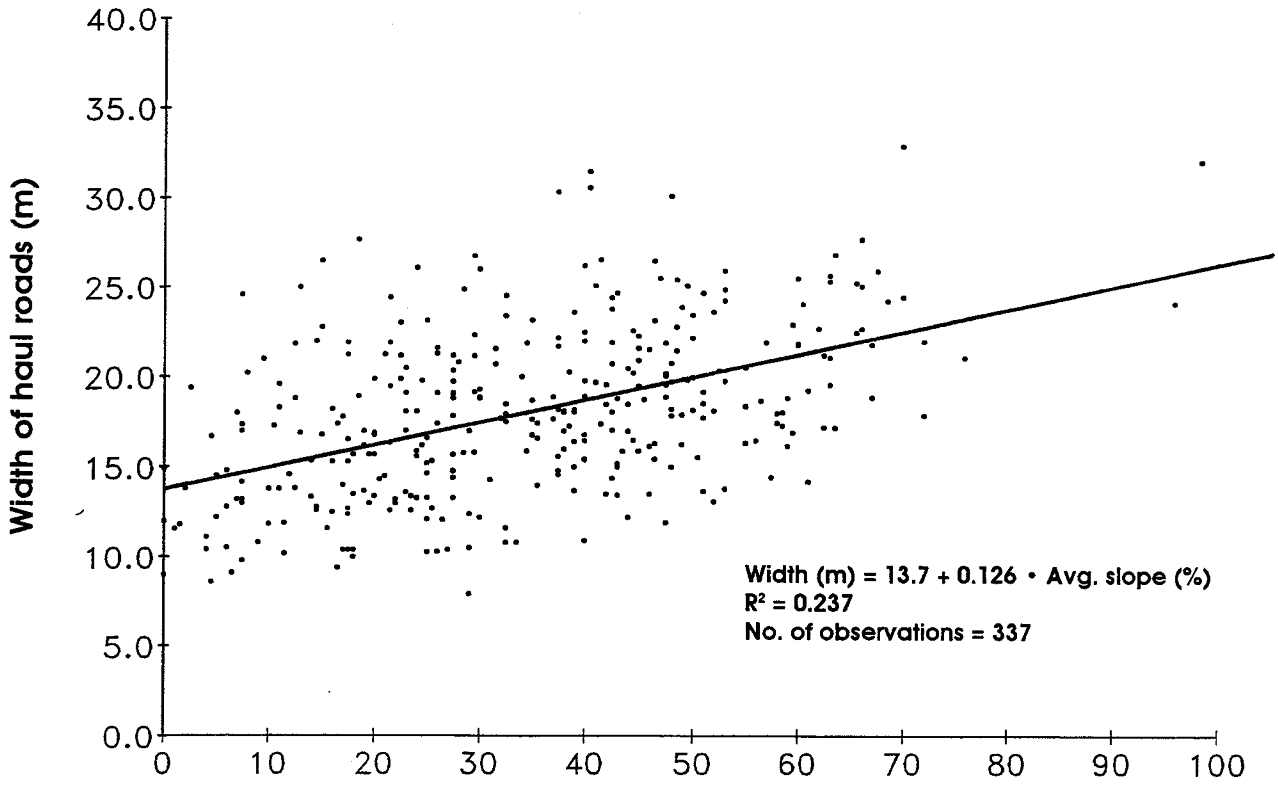

Figure 4. Relationship of total haul-road width and average sideslope.

Table 6. Landings: Data Summary

	Total area (ha)	Working surface area (ha)	Ratio of working surface to total area (ha)
Average	0.120	0.054	0.45
Range	0.039-0.326	0.010-0.116	0.17-0.63
No. of samples	21	21	21

Table 7. Average Width of Backspar Trails, by Slope Class

Slope class (%)	Samples (no.)	Total width (m)
0-5	20	4.3
6-15	50	4.2
16-25	65	4.4
26-35	42	4.7
36-45	22	5.0
46-55	8	6.5
56	4	4.6
	Total: 211	Average: 4.6

sample cross sections were on slopes between 6 and 35%. Crawler tractors or hydraulic excavators were commonly used as mobile backspars on slopes up to 45% on the sites selected for this survey. Stump-rigging prevailed on steeper slopes.

Backspar trails were seldom excavated or bladed on slopes less than about 40%. Therefore, width was measured as the horizontal distance between the outer edges of the track impressions in the duff layers. The width of excavated trails, generally found only on steeper slopes, was defined as the horizontal distance from the top of the cut to the bottom edge of the sidecast, as for haul roads. The overall average width of 4.6 m is about one-third greater than outer track dimensions of typical backspar machines (about 3.3-3.5 m). This suggests, generally, that backspar trails on the sites selected for this survey were carefully constructed and used, i.e., that unnecessary manoeuvring on gentle ground or overbuilding on steeper slopes was infrequent on these sites.

As with haul roads, the relationship between width of backspar trail and slope steepness was also investigated using regression analysis (Figure 5). A linear model with equation

$$width\ (m) = 3.9 + 0.028 \cdot (\%\ slope)$$

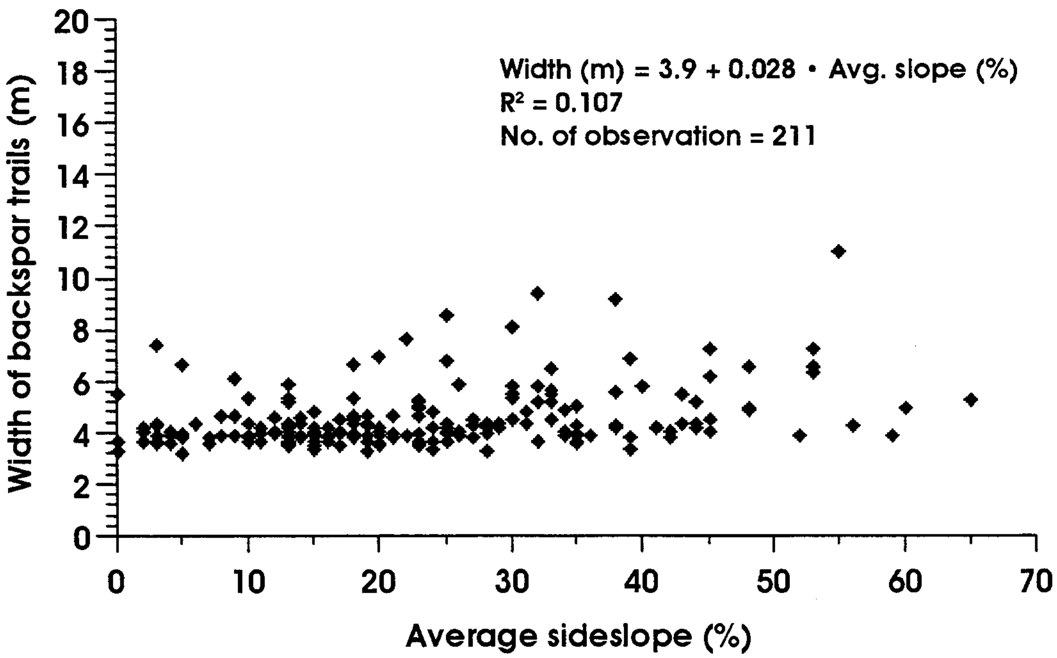

Figure 5. Relationship of total backspar trail width and average sideslope.

provided the best fit. While Table 7 suggests a slight trend of increasing width with increasing sideslope, this relationship is not significant. Only about 11% of the variance associated with width of backspar trails was explained by slope.

Occupancy Levels, by Yarding System

FERIC compared site-occupancy levels for the four yarding systems in three scenarios:

1. Total Site Occupancy - The total area disturbed by all haul roads, landings, and backspar trails, including cuts, running surfaces, and sidecast.
2. Haul Roads and Landings - The total area disturbed by all haul roads and landings, including cuts, running surfaces, and sidecast, but excluding backspar trails.
3. Haul Roads and Landings, Excluding Sidecast - As in Scenario 2 above, but excluding sidecast.

Scenario 1: Total Site Occupancy. This scenario presents and compares the total area affected by roads, landings, and backspar trails for each yarding system. It is stressed that here **total site occupancy is not equivalent to loss of growing site**, as currently defined by the British Columbia Ministry of Forests (BCMOF). Readers should refer to Vancouver Region's guidelines for preparing Pre-Harvest Silviculture Prescriptions (BCMOF 1990, 1991), and to the Regional Soil Conservation Committee, for current definitions of loss of growing site.

Table 8 and Figure 6 present ranges and averages of road, landing, backspar trail, and total occupancies, expressed as a percent of total cutblock area, for the four yarding systems. These occupancy levels were derived for each cutblock by applying the average total widths for haul roads (18.1 m) and backspar trails (4.6 m) and average total area for landings (0.120 ha) to their respective lengths or numbers. The resulting cutblock percentages were then combined to generate yarding-system averages. The average percentages shown in Table 8 are not adjusted for slope.

Grapple yarding, at an average occupancy of 11.8%, has a higher proportion of block area occupied by roads, landings, and backspar trails than grapple/highlead (10.9%) or highlead (9.3%). The similar total occupancy levels result from small offsetting differences between the three systems in haul road, landing, and backspar trail occupancies. Grapple yarding has a greater proportion of area occupied by haul roads and backspar trails, but less in landings, than grapple/highlead and highlead systems. Despite the fact that occupancy ranges for the three systems are large and overlap considerably, Analysis of Variance on transformed data indicates that average total site occupancy for grapple-yarded cutblocks is significantly greater than for highlead and skyline systems.

Skyline cutblocks have a significantly lower total occupancy level (4.5%) than all other systems, due mainly to lower haul-road occupancy.

Scenario 2: Haul Roads and Landings, Including Sidecast. Excluding the area in backspar trails, average site occupancy levels are 10.0% for grapple and grapple/highlead systems and 9.0% for highlead systems, and there is no significant difference between the three systems. Backspar trails accounted for an average of only 0.1% on skyline-yarded cutblocks, so average site occupancy levels are 4.4%.

Scenario 3: Haul Roads and Landings, Excluding Sidecast. Sidecast slopes are the focus of considerable debate at present. The Regional Soil Conservation Committee is developing definitions to enable users to determine what proportion of sidecast area should be counted as contributing to future production. Scenario 2 shows the effects of including all sidecast as nonproductive site. This scenario examines the impact of considering sidecast slopes as productive site.

From Table 5, sidecast accounts for approximately 36% of the weighted average road width of 18.1 metres. On average, therefore, removing sidecast areas from average occupancy levels in Scenario 2 would yield net occupancy levels of about 6.5% for grapple and grapple/highlead cutblocks, 6.0% for highlead cutblocks, and 2.9% for skyline cutblocks.

This analysis is not intended to suggest that sidecast be excluded from the calculation of area withdrawn for permanent access. Rather, it is intended to illustrate the importance of developing workable definitions that distinguish productive from nonproductive sidecast and improve estimates of actual site loss for permanent access networks.

CONCLUSIONS

Based on a survey of 156 cutblocks on Vancouver Island, the Queen Charlotte Islands, and the adjacent mainland South Coast in 1991-1992, the total area occupied by haul roads, landings, and backspar trails averages 11.8% of total cutblock area for grapple-yarding systems and 9.3% for highlead systems. Settings harvested by combinations of these two systems have

Table 8. Averages and Ranges of Occupancy Levels for Haul Roads, Landings, and Backspar Trails, by Yarding System

Yarding system	Samples (no.)	Area occupied by: Haul roads (%)	Landings (%)	Backspar trails (%)	Total (%)	Significance[1]
Grapple	90					
Average		9.5	0.5	1.8	11.8	a
Range		4.4-16.6	0.0-2.5	0.0-5.6	4.9-19.7	
Grapple/highlead	44					
Average		8.7	1.4	0.9	10.9	a b
Range		4.0-10.7	0.6-4.8	0.0-2.5	6.1-15.0	
Highlead	13					
Average		7.4	1.6	0.2	9.3	b
Range		4.1-11.3	0.6-4.3	0.0-1.6	6.0-15.6	
Skyline	9					
Average		3.5	0.9	0.1	4.5	c
Range		0.0-0.3	0.7-2.2	0.0	2.2-10.9	
	156					

[1] Values having the same letter are not significantly different at a 95% confidence level.

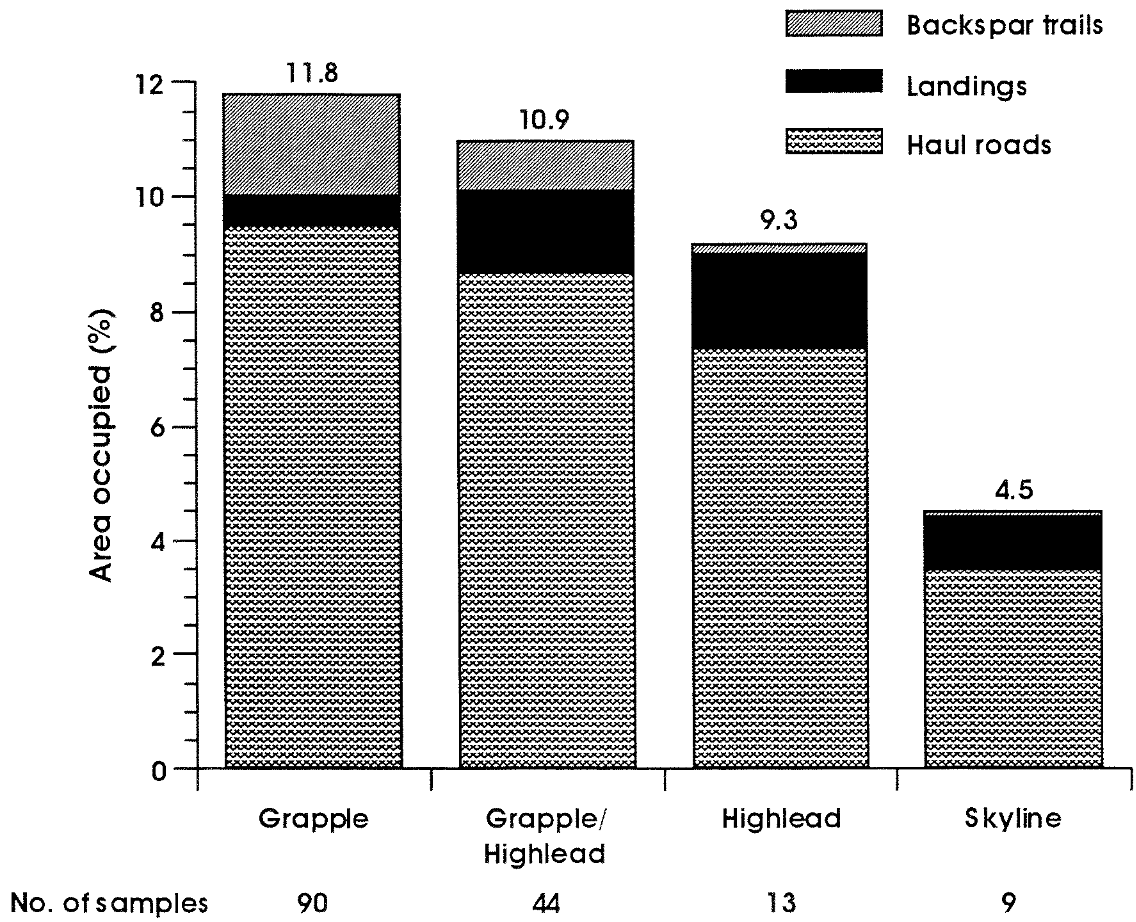

Figure 6. Occupancy levels for haul roads, landings, and backspar trails, by yarding system.

intermediate occupancy levels. The average site occupancy level for skyline cutblocks (4.5%) is much lower, but this estimate is based on small sample size.

While total site occupancy levels for grapple, grapple/highlead, and highlead systems are similar, the proportions due to haul roads, landings, and backspar trails vary. Grapple-yarded cutblocks were characterized by higher densities of haul roads and backspar trails than highlead cutblocks, but highlead cutblocks had more landings.

On average, haul roads accounted for about 80% of total site occupancy for all yarding systems in this survey. Backspar trails were the second largest component of site occupancy on grapple-yarded areas, while landings were the second largest source for grapple/highlead, highlead, and skyline cutblocks.

On a block-by-block basis, haul road, landing, and backspar trail densities are extremely variable. Ranges in these values overlap considerably between the yarding systems, and differences in average density and occupancy values are very minor in comparison. Slope and terrain uniformity obviously affect road and landing densities through their influence on area development and cutblock layout, but the effects are difficult to quantify. The practice of engineering cutblocks for two or more yarding systems, now well established in Coastal British Columbia, may lessen the importance of slope and terrain by increasing layout options. Again, however, the benefit is difficult to estimate.

Overall width of haul roads was found to increase steadily with increasing slope. Widths of ditches tended to decrease with slope, but this was more than offset by increases in cut and sidecast widths. Because haul roads are the largest contributor, total site occupancy levels would be expected to be higher on steeper sites than on gentle sites with similar road densities.

Unlike haul roads, the average width of backspar trails showed only a slight tendency to increase with increasing slope. Reasons for this are not certain but the lack of trend and relatively narrow average width suggest careful construction and use on the sites sampled.

RECOMMENDATIONS

Due to the sampling limitation of this study in respect to geographic location, terrain difficulty, slope range, and cutblock area, further study is needed to expand the data base. Four specific recommendations are:

- Sample more cutblocks for all systems in difficult terrain, and for highlead and skyline systems in particular.
- Further analyse existing and new data to define the impacts of slope and terrain on road, landing, and backspar trail densities, and to assess the potential benefits of using multiple yarding systems.
- Sample more cutblocks in the 0-40 hectare range to examine the effect of cutblock size on occupancy levels.
- Survey more landings to improve the ability to estimate average landing size and to investigate relationships between landing size and slope. Surveys of additional haul road and backspar trail cross sections are also required to refine slope trends with these structures.

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APPENDIX A

Summaries of Statistical Analyses

Appendix A.1
Summary of Statistical Analysis
Cutblock Area

Table A.1.1. Analysis of Variance, Cutblock Area

Source of variation	df	SS	MS	F	
Yarding system	3	3 812.3	1 270.8	1.0	N.S.
Error	152	201 000.6	1 322.4		
Total	155	204 812.9			

Table A.1.2. Duncan's Multiple-Range Test, Cutblock Area

Not applicable

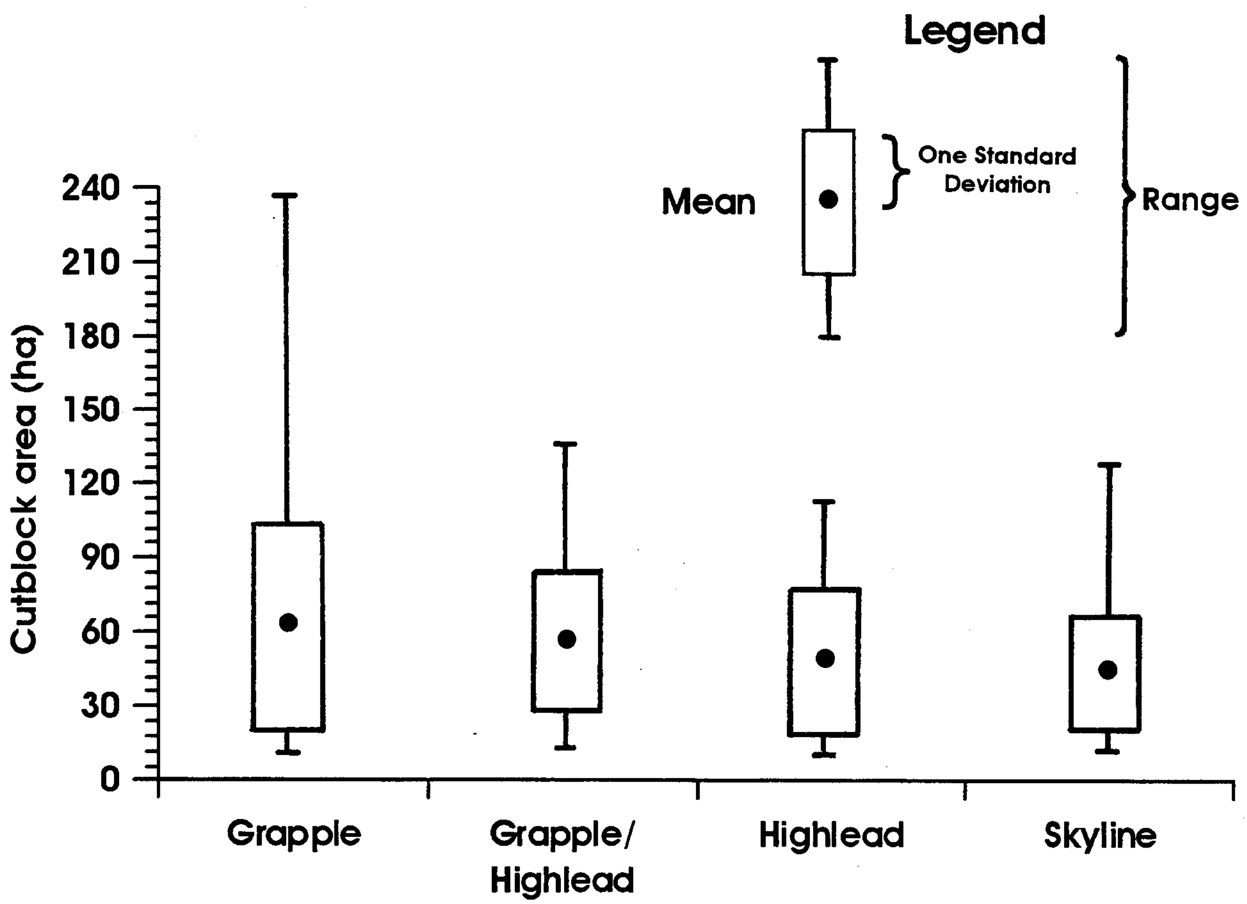

Figure A.1. Comparison of cutblock area, by yarding system.

Appendix A.2
Summary of Statistical Analysis
Density of Haul Roads

Table A.2.1. Analysis of Variance, Density of Haul Roads

Source of variation	df	SS	MS	F	
Yarding system	3	9 711.3	3 237.1	24.3	*
Error	152	20 224.9	133.1		
Total	155	29 936.2			

* = Significant at 95% confidence level.

Table A.2.2. Duncan's Multiple-Range Test, Density of Haul Roads

	Yarding system				
	Grapple (m/ha)	Grapple/Highlead (m/ha)	Highlead (m/ha)	Skyline (m/ha)	
Range	52.1	47.6	40.7	19.1	*
Significance	a	ab	b	c	

* = Means having the same letter are not significantly different at 95% confidence level.

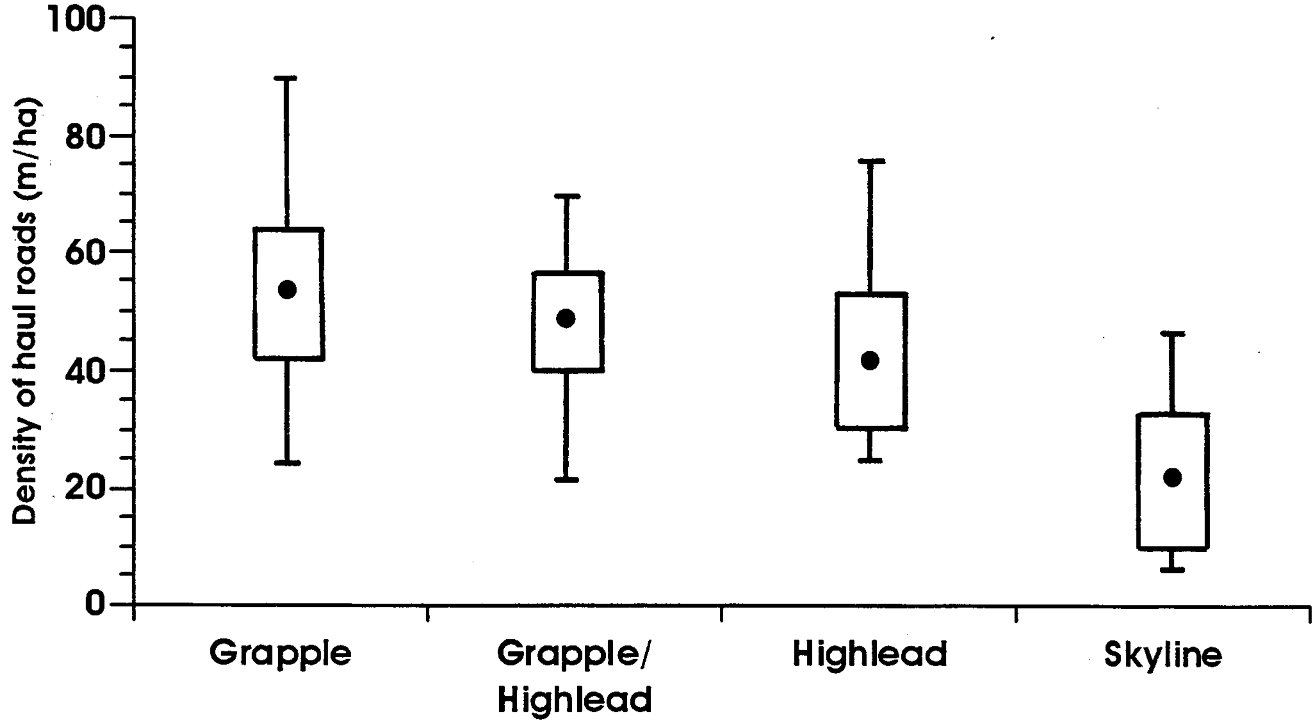

Figure A.2. Comparison of haul-road density, by yarding system.

Appendix A.3
Summary of Statistical Analysis
Landings

Table A.3.1. Analysis of Variance, Landings

Source of variation	df	SS	MS	F	
Yarding system	3	647.0	215.7	13.4	*
Error	152	2 441.6	16.1		
Total	155	3 089.6			

* = Significant at 95% confidence level.

Table A.3.2. Duncan's Multiple-Range Test, Landings

	Yarding system				
	Grapple (no. landings)	Grapple/Highlead (no. landings)	Highlead (no. landings)	Skyline (no. landings)	
Range	2.3	6.3	7.3	3.4	*
Significance	a	b	b	a	

* = Means having the same letter are not significantly different at 95% confidence level.

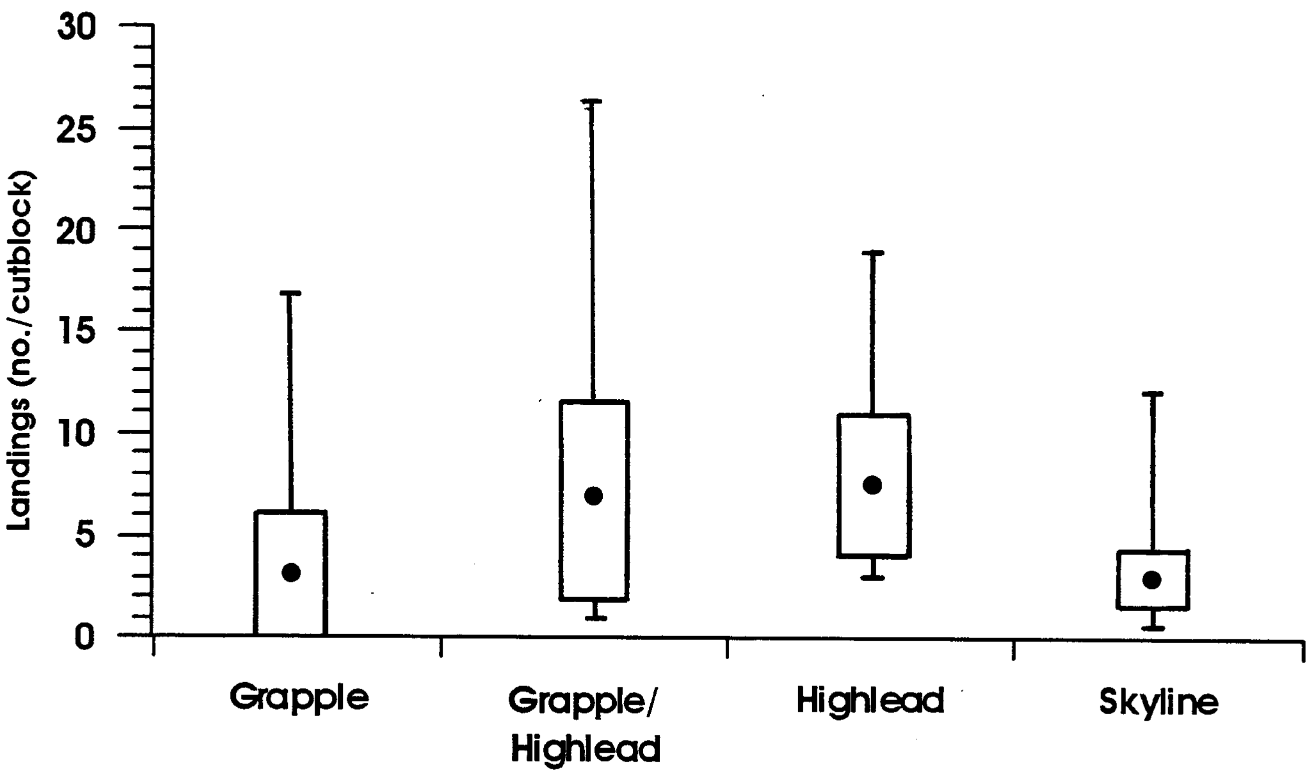

Figure A.3. Comparison of average number of landings, by yarding system.

Appendix A.4
Summary of Statistical Analysis
Density of Backspar Trails

Table A.4.1. Analysis of Variance, Density of Backspar Trails

Source of variation	df	SS	MS	F	
Yarding system	3	29 519.0	9 839.7	19.5	*
Error	152	76 556.1	503.7		
Total	155	106 075.1			

* = Significant at 95% confidence level.

Table A.4.2. Duncan's Multiple-Range Test, Density of Backspar Trails

	Yarding system				
	Grapple (m/ha)	Grapple/Highlead (m/ha)	Highlead (m/ha)	Skyline (m/ha)	
Range	39.7	19.8	3.3	1.3	*
Significance	a	b	c	c	

* = Means having the same letter are not significantly different at 95% confidence level.

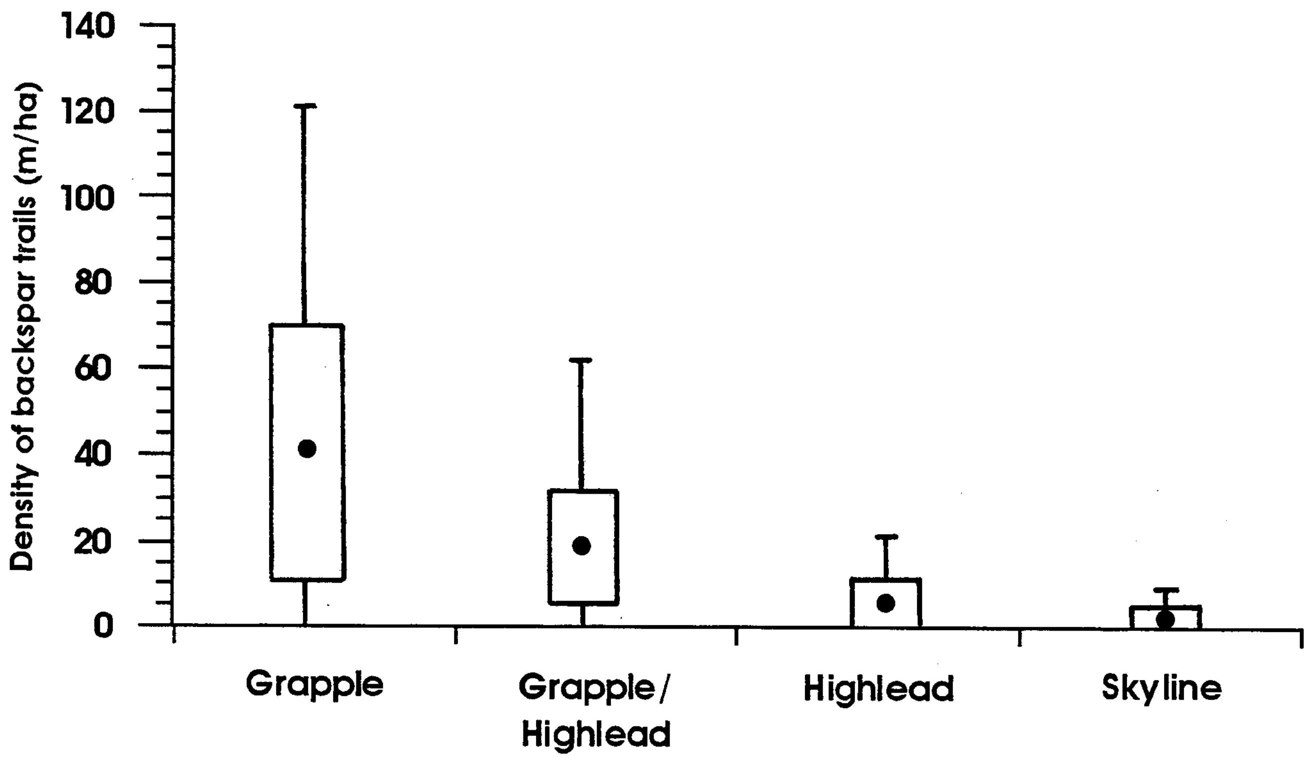

Figure A.4. Comparison of backspar trail density, by yarding system.

Appendix A.5
Summary of Statistical Analysis
Site Occupancy Including Backspar Trails[1]

Table A.5.1. Analysis of Variance (transformed data), Site Occupancy Including Backspar Trails

Source of variation	df	SS	MS	F	
Yarding system	3	581.1	193.7	32.9	*
Error	152	893.6	5.9		
Total	155	1 474.7			

* = Significant at 95% confidence level.

Table A.5.2. Duncan's Multiple-Range Test (transformed data), Site Occupancy Including Backspar Trails

	Yarding system				
	Grapple (deg)	Grapple/Highlead (deg)	Highlead (deg)	Skyline (deg)	
Range	20.0	19.1	17.8	11.8	*
Significance	a	ab	b	c	

* = Means having the same letter are not significantly different at 95% confidence level.

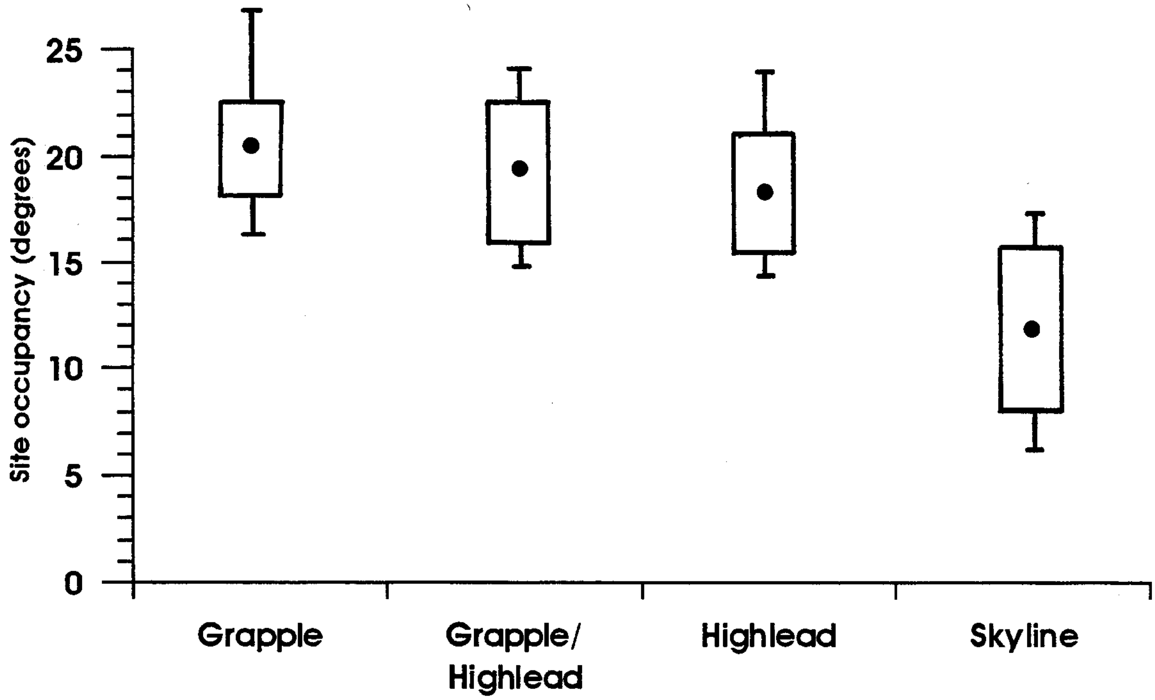

Figure A.5. Comparison of site occupancy, including backspar trails, by yarding system.

[1] Percent site occupancy data were converted into degree data using an arcsine transformation procedure. Analyses were performed on the transformed (degree) data, and results are also summarized here using degree data.

Appendix A.6
Summary of Statistical Analysis
Site Occupancy Excluding Backspar Trails[1]

Table A.6.1. Analysis of Variance (transformed data), Site Occupancy Excluding Backspar Trails

Source of variation	df	SS	MS	F	
Yarding system	3	376.5	125.5	26.2	*
Error	152	729.9	4.8		
Total	155	1 104.4			

* = Significant at 95% confidence level.

Table A.6.2. Duncan's Multiple-Range Test (transformed data), Site Occupancy Excluding Backspar Trails

	Yarding system				
	Grapple (deg)	Grapple/Highlead (deg)	Highlead (deg)	Skyline (deg)	
Range	18.3	18.4	17.7	11.7	*
Significance	a	a	a	b	

* = Means having the same letter are not significantly different at 95% confidence level.

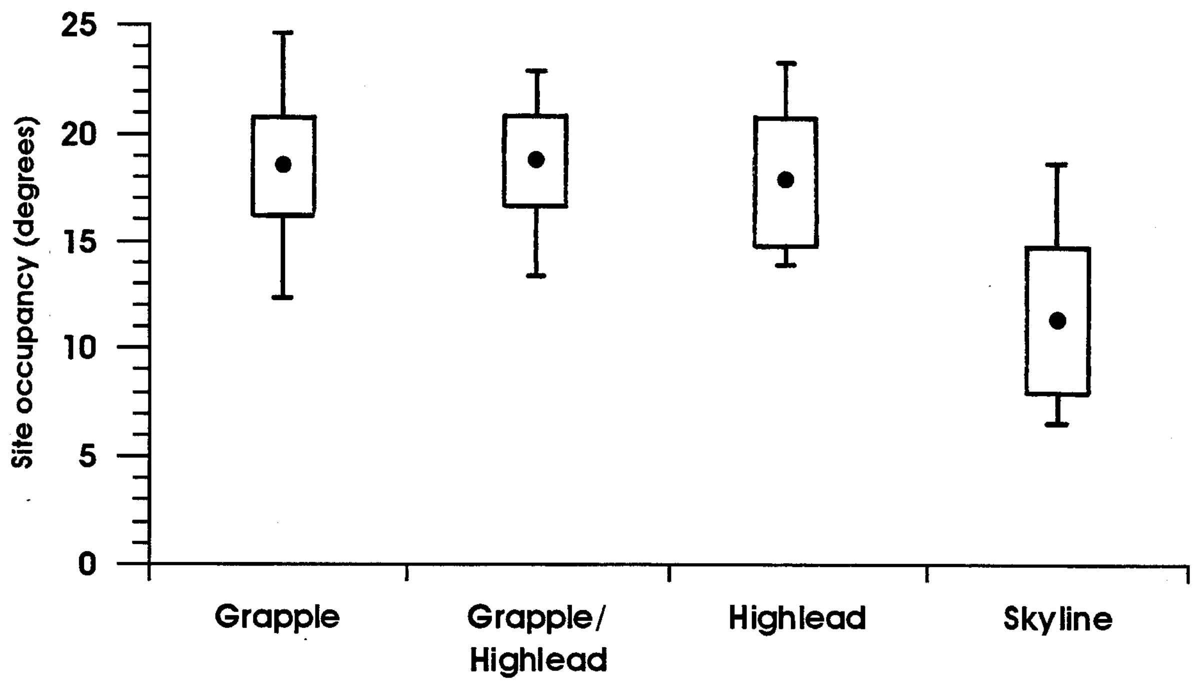

Figure A.6. Comparison of site occupancy, excluding backspar trails, by yarding system.

[1] Percent site occupancy data were converted into degree data using an arcsine transformation procedure. Analyses were performed on the transformed (degree) data, and results are also summarized here using degree data.