Arctic Development

Timber Harvesting Techniques That Protect Conifer Understory In Mixedwood Stands: Case Studies

Type of Study: Primary Production

Date of Report: 1992

Author: Gov't Of Alberta

Catalogue Number: 4-8-21

Forestry
4-8-21

Canada Alberta

Partnership Agreement in Forestry
Entente d'association en foresterie

TiMBER-HARVESTING TECHNIQUES THAT PROTECT CONIFER UNDERSTORY IN MIXEDWOOD STANDS: CASE STUDIES

March 1992

Canada Alberta

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INTRODUCTION

This report presents cost and productivity results, as well as results about the harvesting-related damage incurred by the understory in a mixedwood harvesting trial. The trial compared conventional and Scandinavian harvesting equipment, levels of operational supervision, and special operational techniques. The study took place in the northern boreal forest region of Central Alberta during 1988 to 1990 and was carried out by the Forest Engineering Research Institute of Canada (FERIC) for Forestry Canada's Northern Forestry Centre.

The mixedwood stands in Central Alberta are an important source of fibre to the Alberta forest industry (Figure 1). The stands contain mature components of white spruce *(Picea glauca (Moench) Voss)* and aspen *(Populus tremuloides (Michx.))*—which are utilized for lumber, panel boards, market pulp, and newsprint—and an immature white spruce understory. In addition, the stands can contain black poplar *(Populus balsamifera L.)* and white birch *(Betula papyrifera Marsh.),* which have limited commercial value at present. The conifer overstory and understory can grow in dense pure stands, clumps, or as scattered stems mixed with other species.

Figure 1. Mixedwood stand in Central Alberta.

The concern facing Alberta's forest industry regarding the mixedwood land base - which can produce 250 to 350 m^3 per ha - is that current harvesting methods can result in these stands reverting to a hardwood status after harvesting. This is caused by two factors. First, conventional harvesting equipment damages the white spruce understory during the harvesting process so that immature stems do not survive. Secondly, after harvesting, the aspen naturally and vigorously regenerates by suckering. This competition to conifer seedlings increases regeneration costs for conifer plantations.

Prior to 1985, and the introduction of extensive aspen utilization in Alberta, forest operations harvested the species required by their mills and left the unwanted trees standing on the site. When mixedwood stands were harvested, this resulted in higher per unit costs than when harvesting pure stands because additional time and effort was required to avoid or sort nonmerchantable pieces; plus, freed costs were allocated over a lower volume of harvested fibre. The potential to reduce harvesting costs in mixedwood stands occurred when the aspen-based fibre industry was introduced in Alberta, and markets became available for both conifer and hardwood species. It was at this point, when large areas of the mixedwood land base were being planned for harvest, that the lack of success in re-establishing white spruce by planting, and the consequent unintentional conversion of mixedwood stands to hardwoods following conventional harvest, became a concern to Forestry Canada and Alberta Forestry, Lands and Wildlife.

In 1987, Forestry Canada's Northern Forestry Centre and the Alberta Forestry, Lands and Wildlife invited Weyerhaeuser Canada Limited (Alberta Division), Blue Ridge Lumber (1981) Ltd., Weldwood of Canada Limited (Hinton Division), Millar Western Industries Ltd., and the Forest Engineering Research Institute of Canada (FERIC) to participate in a cooperative study to investigate rnixedwood harvesting practices. The study was partially funded under the Canada-Alberta Forest Resource Development Agreement (FRDA). A Spruce Understory Steering Committee, consisting of the seven project participants, was organized to manage the project. Participants had the following responsibilities:

- Forestry Canada provided baseline inventory information on the preharvest understory and overstory, and monitored harvesting-related damage on the remaining understory immediately after harvesting. In addition, Forestry Canada would continue to monitor the understory in the study areas to assess the longer-term impact of harvesting on understory survival and growth.
- Alberta Forest Service and the industry cooperators selected three study locations that represented typical mixedwood stands in Central Alberta.
- Industry cooperators prepared harvesting plans for the study sites, and arranged and supervised harvesting operations.
- FERIC monitored harvesting operations, documented production, provided technical advice to the harvesting operators, and determined the costs for the harvesting methods utilized.

The steering committee agreed to focus on harvesting methods that utilized as much of the existing mechanical harvesting equipment as possible. Study participants wanted to understand the limitations of the feller-buncher and grapple skidder before looking at alternative equipment such as Scandinavian harvesters and forwarders. In addition, the harvesting operations were to be conducted while temperatures were above -15°C. The Spruce Understory Steering Committee participants discussed the benefits of avoiding wet ground until there was enough frost to reduce rutting and soil compaction. During the field trials, operating practices were altered to accommodate equipment scheduling. In some cases, operations were successfully conducted during periods of hard frost, and in others, during summer on drier sites.

Study Goals and Objectives

The main purpose of the study was to determine whether alternative harvesting methods could be used to limit the destruction of white spruce understory, and leave the remaining residuals in a healthy, windfirm state following overstory harvest. The reason for attempting to preserve the immature spruce is to minimize the cost of establishing a white spruce stand to a free-to-grow stage, and the risk of plantation failure. As a result, the project was directed toward using the white spruce understory as the basis for regeneration stocking. Typically, the white spruce understory can be up to 50 years old and have a density of 200-2000 sterns per hectare at 2.5 cm or greater diameter at breast height (dbh). Assuming that all spruce over 25-cm dbh would be harvested, a range of immature white spruce 2.5-25 cm dbh would be left having a density of 200-1000 stems per hectare (Brace and Bella[1]).

The primary activities of participants included monitoring productivity, costs, and understory damage associated with specific harvesting methods.

The expected benefits of effective understory protection include:

- The silvicultural costs of re-establishing conifer stems for a mixedwood stand would be significantly reduced if the understory could be preserved. And the need to mechanically treat competing aspen suckers and grass would be reduced.
- Utilization of the established conifer regeneration would reduce crop rotation time as well as the risks associated with establishing a plantation. However, if infill planting was required or initiated, the harvest age would depend on the youngest trees comprising the new stand.
- Companies requiring conifer fibre would have more accurate inventories of immature stands.
- The remaining understory stands would provide habitat and cover for wildlife and birds, mitigate the visual effects of clearcut harvesting, and provide recreational sites.

Drawing from these study objectives, the primary objectives of FERIC was to determine whether conventional harvesting equipment can be used to protect the white spruce understory when the mature overstory is harvested, and at what associated costs. Aspects that FERIC investigated were:

- Productivity, costs, and operational advantages and disadvantages associated with using both conventional and Scandinavian harvesting equipment.
- Differences in understory protection associated with conventional and Scandinavian harvesting equipment.
- Effectiveness of preharvest planning and more intensive supervision in protecting understory.
- Effectiveness of using designated skid trails, leaving rub stumps beside the skid trails, and topping and limbing stems in the bush on understory protection.

The primary objectives of Forestry Canada were to determine the preharvest inventory for all study sites, establish permanent sample plots, assess understory damage caused by harvesting activity, and conduct longer-term assessments of wind stability and growth.

STUDY METHODS

Sites

The study participants chose three Alberta sites: Drayton Valley, Hinton, and Blue Ridge (Figure 2). Each site, or case study, consisted of 50-60 ha containing relatively uniform terrain and understory stands. Each study area was divided into three parcels: one control block and two treatment blocks.

The control blocks were harvested in the conventional manner with no regard to understory protection. This served as the basis for comparing productivity and costs for alternate harvesting

[1] Brace, L.G. and Bella, I.E. 1988. "Understanding the Understory: Dilemma and Opportunity," in ***Management and Utilization of Northern Mixedwoods; Proceedings of a Symposium.*** J.K. Samoil, editor. Can. For. Serv., North. For. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-296.

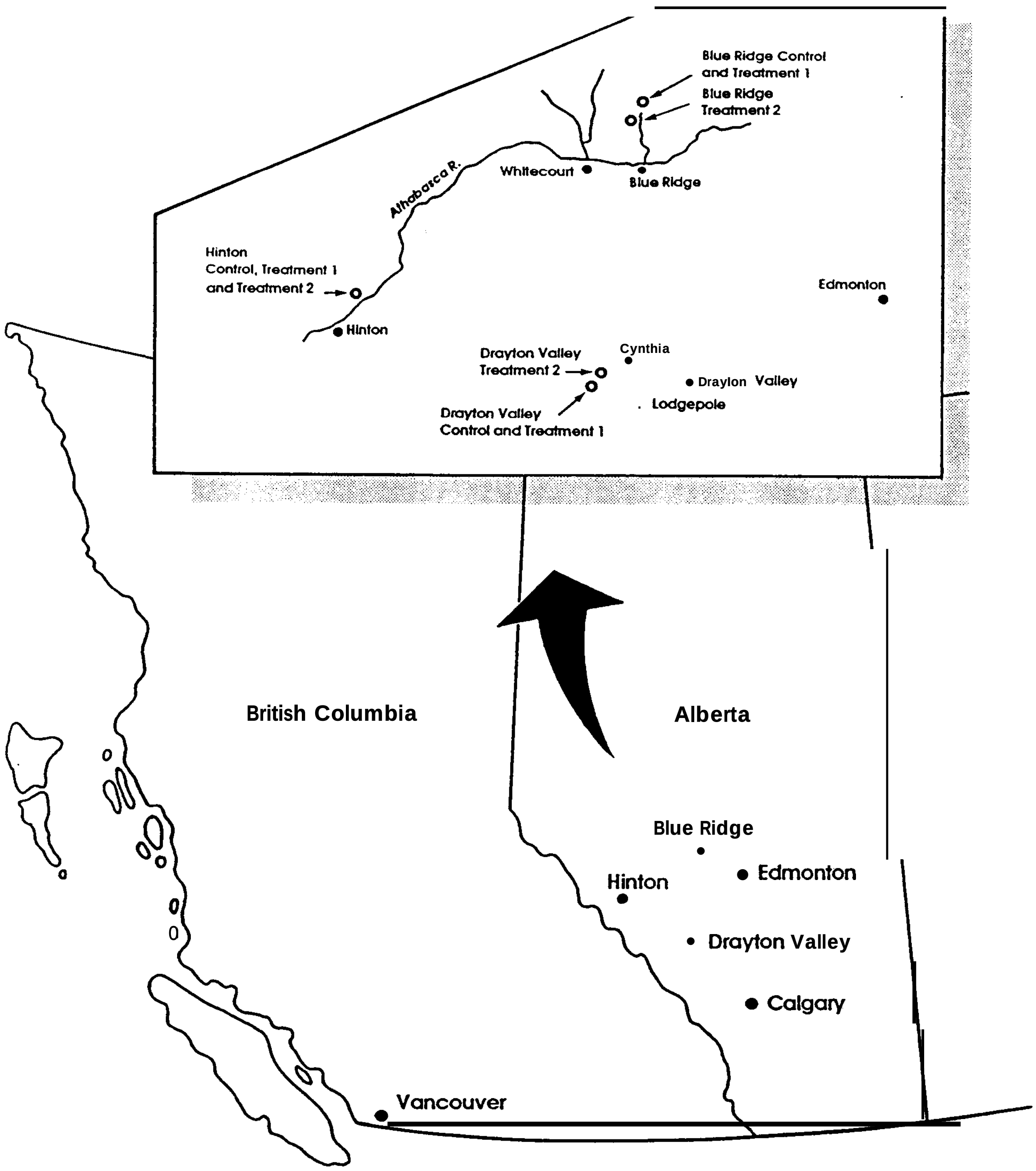

Figure 2. Locations of study sites.

methods used on the first and second treatment blocks. The alternate harvesting methods, aimed at achieving the report's objectives, were designed by the industry cooperators in conjunction with FERIC. All final harvesting prescriptions were presented to the Steering Committee (consisting of FERIC; four industry cooperators; Alberta Forestry, Lands and Wildlife; and Forestry Canada) for approval before harvesting.

Prior to harvesting, Forestry Canada flagged the boundaries for each of the three study sites, and established regeneration and inventory plots according to Alberta Forest Service standards. Plots were located every 61 m along survey lines spaced 61 m apart. A steel pin was driven into the ground at each plot's centre. At each sample point on the grid, the stocking level of white spruce 0.5 m and taller was determined using a 1.8 m radius plot, and on every second sample point a 6.0 m radius plot was established at which all conifers 0.5 m and taller were tagged, diameters at breast height (dbh) and height were measured, the dbh of all deciduous trees was measured, and the height of deciduous trees was sampled.

After harvesting, a metal detector was used to relocate the steel pins that marked the plot centres so that any changes in the status of white spruce understory or mature stems could be recorded. For summary purposes, the residuals were classified as: undamaged if they exhibited no or minor injury; injured if they exhibited an injury that would reduce growth, but would not be life threatening to the residual; and destroyed if the residual was either not present at the time of the survey or was too severely injured to survive as a crop tree. Residuals removed during loading, skid-trail, and road construction were included in the destroyed category. (Appendix I summarizes the darnage factors assessed at the three sites.)

During the harvesting trials, a FERIC researcher was stationed full-time at each study site to collect all machine-time and production information, and to evaluate the effectiveness of various special treatments. In addition, the researcher provided assistance in planning and conducting special treatments.

Productivity and Cost

Shift-level time and production information was collected on a daily basis. All feller-bunchers, harvesters, skidders, forwarders, and the delimber at Blue Ridge, were equipped with DSR Servis Recorders. Other equipment (bulldozers, mechanical slasher, and the delimber at Hinton) and manual labourers (hand fellers, manual slashing, preharvest layout, and supervision) were monitored as they worked on the various blocks, and their working hours recorded in a diary. The FERIC researcher completed a daily form detailing date, operating area, weather, production counts, reasons for any interruptions and breakdowns greater than 15 minutes, and comments on other factors affecting production. The Servis Recorder charts were coded and summarized to generate time and production summaries for each harvesting machine, and all data were entered onto spreadsheets for computer analysis.

Shifts were categorized according to whether they were productive or non-productive. A shift with any amount of production time was classified as a production shift. A non-production shift was classified as one that was originally scheduled for production, but some events, such as repairs, the lack of operating inventory, or an operator, prevented the machine from working. Scheduled shifts off included weekends and statutory holidays.

Total time for shifts with production were further sub-divided into three categories; namely operating time, mechanical delay time, and nonmechanical delay time. Operating time (operating hours) included the time equipment or manpower was in motion performing its prime function or a related activity (such as traveling to or from the work site, or reconnoitering the block). Mechanical delay time was associated with daily servicing, refueling, repairs, and waiting for parts or mechanics. Nonmechanical delay time consisted of two components. The first component included operational delays such as planning, which was a routine delay required to complete the work; the second component included operator delays, e.g. when the operator left his machine for personal reasons. The description of the timing elements for shift-level studies are summarized in Appendix II.

The FERIC researcher also conducted detailed work-sampling studies for each machine throughout the harvesting studies. This information was summarized and provided a breakdown of cycle times that indicated changes in work patterns from one harvesting method to another. The descriptions for the cycle-time elements monitored during the work-sample studies are summarized in Appendix III.

Hourly machine costs for all harvesting equipment were calculated using a FERIC standard costing formula and are summarized in Appendix IV. However, these rates are not the actual costs incurred by the company or contractor, and do not include such costs as crew and machine transportation, overhead, profit and risk. While these items are real costs that must be included in determining actual harvesting costs, many organizations use their own formulae (different from FERIC's) for calculating such costs, and it is left to readers to supply the figures most appropriate for their own needs. Interest charges are shown in the costing tables, but are excluded from the costs of production. New machine prices and salvage values were obtained from equipment dealers in Central Alberta. Repair, maintenance, fuel, and lubricant costs were either provided by the contractor or based upon information supplied by equipment distributors.

Hourly rates for equipment operators were set at $18, while a rate of $27 per hour was assigned to hand fellers and bush-limbers. These rates were based on 1990 Weldwood of Canada Limited harvesting rates. Supervision and planning costs were rated at $400 per day. Hand-buckers (manual slashers) were assigned a daily rate of $220 per shift. The daily rates were obtained from discussions with the contractors, companies, and crew who participated in the studies. These rates may not reflect the actual hourly rates paid to Alberta woodworkers, as most companies and contractors pay their employees on the volume of wood produced.

Equipment availability (the percentage of time a machine was mechanically available for work) was calculated by:

$$\frac{(\text{total scheduled machine hours - total mechanical delays}) \cdot 100}{\text{total scheduled machine hours}}$$

Utilization (the proportion of scheduled machine hours the equipment was actually doing productive work) was calculated by:

$$\frac{(\text{productive machine hours}) \cdot 100}{\text{total scheduled machine hours}}$$

SYNOPSIS OF HARVESTING STUDIES

This report summarizes the results of case studies for Drayton Valley, Hinton, and Blue Ridge, with a range of controls, treatments, and harvesting methods. ***Table 1 is an especially useful***

Table 1. Harvesting Prescriptions: Summary

Item	All Case Studies Control	Drayton Valley Treatment 1	Drayton Valley Treatment 2	Hinton Treatment 1	Hinton Treatment 2	Blue Ridge Treatment 1	Blue Ridge Treatment 2
pm-harvest planning.	Only as required for harvest approval.	Pre-located main skid trails and landings.	Pre-located main skid trails and landings.	Pre-located main skid trails and landings.	Harvester operator selected trailways.	Pre-located main skid trails and landings.	Harvester operators selected trailways.
Understory protection.	No understory protection.	Intermediate understory protection.	Intermediate understory protection.	High understory protection.	High understory protection.	High understory protection	Intermediate understory protection.
Harvest operations supervision.	Minimal.	Minimal.	Minimal.	Continuous daily supervision.	Contractor self-srrpervised.	Continuous daily supervision.	Operators self-supervised.
Reading required.	As for Treatment 1 in the respective study area	Followed existing seismic lines.	Followed existing seismic lines.	Only access to one landing required a spur road.	None required.	Loop road with spurs required to access landings.	None required.
Payment method.	As for Treatment 1 in the respective study area.	Piece rate ($/m^3) for au crew.	Piece rate ($/m^3) for au crew.	Hourly rate for all crew.	Piece rate ($/m^3) for all crew.	Hourly rate for all crew.	Piece sate ($/m^3) for all crew.
Equipment:							
Falling	As for Treatment 1 in the respective study area	Aspen felled with shear-equipped front-end loader feller-buncher. Hand felf conifer.	Aspen arrd conifer felled with shear-equipped front-end loader feller-buncher.	Asperr and conifer felled with excavator-type feller-buncher.	Double-grip harvester felled all trees.	Aspen and conifer felled with excavator-type feller-buncher.	Single- and double-grip harvesters felled all trees.
Skidder	As for Treatment 1 in the respective study area.	Grapple skidders.	Grapple skidders.	Grapple skidders.	10-t forwarder.	Grapple skidders.	Two 10-t forwarders.
Limbing	Drayton Valley: As for Drayton Valley Treatment 1. Hinton and Blue Ridge: Aspen and conifer delimbed at roadside landing with stroke delimber.	Aspen manually delimbed at landing. Conifer delimbed at landing using skid&r blade.	Aspen and conifer stems rough delimbed and topped either at the site, or prior to the bunches entering the landing area	Aspur and conifer manually rough delimbed and topped at felling site and stroke &limbed at roadside.	At felling site during felling.	Aspen and conifer manually rough delimbed and topped at felling site and stroke delimbed at landing.	At felling site during felling.
Processing	As for Treatment 1 in the respective study area	Aspen hand-slashed at landing into 2&m lengths. Conifer cut to tree-length at landing.	Aspen hand-slashed at landing into 2.6-m lengths. Conifer cut to tree-length at landing.	Aspen slashed into 2.6-m lengths at roadside. Conifer tree-length at roadside.	Aspen cut to 2.6-m length at felling site. Conifer art to log-lengths at felling site.	Aspen and conifer cut to log-length at landing.	Aspen cut to 2.6-m lengths at felling site. Conifer cut to log-lengths at felling site.

reference guide when reading any section of the results that follow. The following brief discussion on silvicultural and harvesting prescriptions is provided as background information for the case studies. The silvicultural prescriptions describe the type of forest to be regenerated after the harvesting operation, and the work required to accomplish these goals. The harvesting prescriptions outline how the harvesting operations would be undertaken to meet the silvicultural prescription.

Silvicultural Prescriptions

Prior to the preparation of detailed harvesting plans, the industry cooperators, Forestry Canada, and Alberta Forestry, Lands and Wildlife developed silvicultural prescriptions for each block. While these prescriptions were very general for the Drayton Valley and Hinton study areas and Blue Ridge Treatment 2 block, a detailed prescription was prepared by Forestry Canada for the control and Treatment 1 blocks at Blue Ridge. Appendix V outlines the generalized silvicultural prescriptions prepared for the case study areas.

Control blocks on coniferous land base were to be clearcut and re-planted only with white spruce or pine to regenerate them to acceptable conifer stocking standards. Control blocks on deciduous land base would be left for regeneration by aspen suckering. Any conifer understory remaining after harvesting would become supplemental growing stock in a regenerated deciduous stand. Treatment to reduce aspen and grass competition would be undertaken as needed.

Treatment blocks were to be regenerated as mixedwood areas, with the proportion of conifer stems increased, if possible. The need for vegetation control was to be minimized by leaving as much ground as possible undisturbed and shaded, and by using the current immature conifers that were greater than 2.5 m in height as regeneration.

Treatment represented the first harvest stage of a two-stage harvesting and tending model (Brace and Bella, 1988) that will perpetuate the mixedwood land base for up to 60 years, at which time the released understory spruce will become merchantable. One practical result is to reduce the costs and risks of spruce plantation establishment and tending, which are required to convert from a mixedwood to a coniferous land base. This is achieved by protecting the natural spruce on the site during first-stage harvesting and by accepting aspen seedling and sucker regeneration in areas not stocked with spruce. This procedure should enhance the spruce component of the stand by increasing the growth and yield of released spruce, and by natural seeding in of spruce under aspen. Fill-in planting and tending would be conducted only on areas found by follow-up survey to be understocked to acceptable hardwood or coniferous species.

The treatment offers an experimental demonstration of timber production, wildlife habitat, and landscape aesthetic aspects of mixedwood land base management, while maintaining the option to change to either hardwood or coniferous land base management.

Harvesting Prescriptions

The control blocks were to be harvested, with no regard to understory protection, using feller-bunchers and grapple skidders. The productivity and understory darnage data collected from the control blocks was to be the baseline information to which the results from the treatment blocks would be compared. The treatment blocks were harvested to demonstrate the effects of pre-locating skid trails, limbing and topping stems prior to skidding, leaving rub stumps beside the skid trails, employing on-site supervision, and the effects different types of harvesting equipment would have on white spruce understory damage, harvesting production, and costs.

Harvesting prescriptions were prepared by the industry cooperators and FERIC, and are summarized in Table 1. Although treatments were generally agreed upon prior to the study, modifications were made as specific trials progressed.

The harvesting prescriptions were prepared to demonstrate the effectiveness of using the most popular Central Alberta harvesting equipment to preserve white spruce understory. Although the combination excavator-carrier/feller-buncher is the most popular felling unit in Central Alberta, several crawler front-end loaders are equipped with feller-buncher attachments. One of the latter units was selected for work at Drayton Valley because the buncher had a narrow machine width that made it more manoeuvrable in confined spaces. During the mixedwood trials, only two Scandinavian harvesters were available in Alberta, and both were based out of Whitecourt. The seven study participants wanted to evaluate the Scandinavian equipment because it was new to Alberta, and they wanted to determine how effectively it could operate in the mixedwood stands.

DRAYTON VALLEY CASE STUDY

Background

The main focus of this case study was to document the differences in understory protection and harvesting costs that result when using conventional roadside harvesting equipment operated by a minimally supervised crew, to similar equipment and crew working with two different prescriptions. The frost prescription used a network of designated skid trails instead of a random network, and the second prescription (Treatment 2) combined the designated skid-trail network with special practices to minimize understory damage.

The Drayton Valley study area consisted of two sites located 45-50 km west of Drayton Valley, Alberta (near the towns of Cynthia and Lodgepole), in the W6 region of the Whitecourt Forest District (Figure 2). The larger area was divided into two harvesting blocks (a control and Treatment 1) and the smaller area was designated Treatment 2 (Figure 3). The general silvicultural prescriptions prepared for this case study are summarized in Appendix V.

The density of white spruce understory between 2.5 and 14 m high at Drayton Valley ranged between 312-569 stems per ha, and was considered light to moderately stocked. Overall, the white spruce understory density ranged between 312-569 stems per ha throughout the study areas. However, the understory was usually located in dense clumps that had densities that ranged between 1500-2300 stems per ha. The areas of understory surrounding these dense clumps had densities that ranged between 250-1000 stems per ha. The white birch was concentrated to the eastern portion of the control block and ranged between O-796 stems per ha. Table 2 summarizes the preharvest stand conditions for each study block.

The aspen overstory on the control and Treatment 1 blocks was overmature, with rot present. This increased the stem breakage during felling. Black poplar and white birch stems were not deliberately felled on any of the blocks.

Overall, the terrain was level, except for southern portions of the control and Treatment 1 blocks which had slopes between 10-25%. The ground was not frozen when the control and Treatment 1 blocks were harvested; however, the ground on Treatment 2 block was frozen. The harvesting equipment had no difficulty moving around any of the blocks.

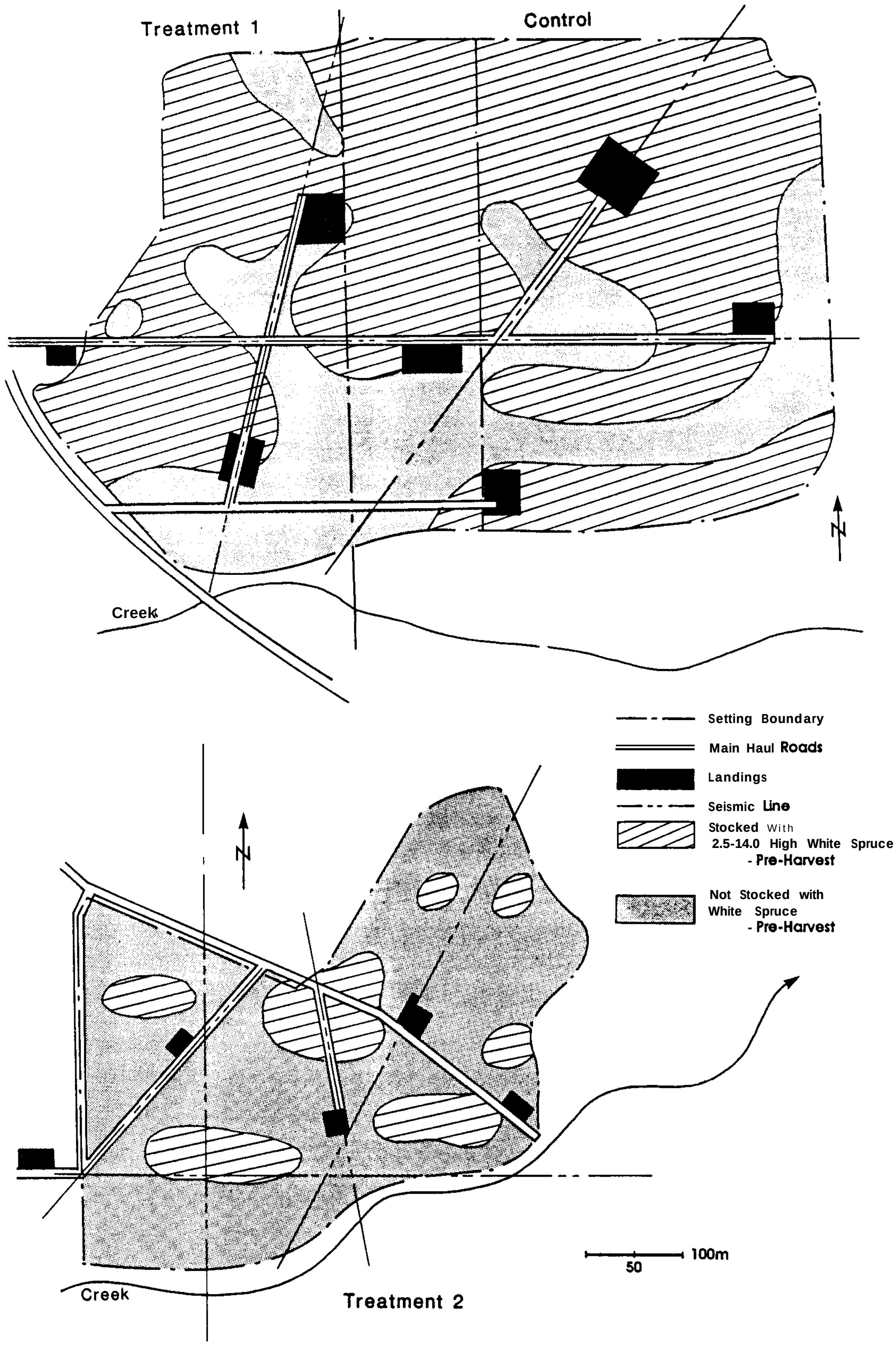

Figure 3. Block layout at Drayton Valley study site.

Table 2. Stand Conditions for Drayton Valley Case Study: Summary (Brace 1989)'

	Control	Treatment 1	Treatment 2
Area harvested (ha)	20	20	15
White spruce understory density (stems/ha) between 2.5-14.0 m height	569	405	312
Stand density (stems/ha)			
Aspen	140	243	282
Black poplar	395	216	118
White birch	136	14	575
White spruce (14+ m high)	27	14	42
Black spruce	0	0	7
Lodgepole pine	2	0	17
Total	700	487	1 041
Merchantable volume (m^3/ha)			
Aspen	112	167	152
White spruce (14+ m high)	37	25	8
Black spruce	0	0	1
Lodgepole pine	5	0	22
Total merchantable volume	159	192	183
Nonmerchantable hardwood	119	47	33
Merchantable volume per stem (m^3)			
Aspen	0.80	0.69	0.54
White spruce (14+ m high)	1.37	1.79	0.19
Black spruce	0	0	0.10
Lodgepole pine	2.5	0	1.31

[a] Brace, L.G. 1989. Results of pre- and post-harvesting data collected by Forestry Canada, Northern Forestry Centre. Unpublished.

All aspen trees over 10-cm diameter and all conifer trees over 25-cm diameter were felled. The harvesting contractor supplied 2.6-m aspen bolts and tree-length conifer logs to Weyerhaeuser Canada Limited's oriented strand board mill and sawmill at the town of Drayton Valley. The contractor subcontracted some of the skidding. All crew members were paid on a piece-rate basis according to the volume of wood delivered to the mill.

Preharvest area planning and harvesting supervision was undertaken by Weyerhaeuser. The blocks were harvested between October and December 1988.

The contractor used the network of seismic lines that criss-crossed all the blocks as roads to access individual landings. Each skidder operator and bucking crew required a separate area to deck their logs to allow accurate payment.

The contractor used a tracked, John Deere JD755 front-end loader equipped with a 46-cm Harricana shear to fell and bunch the aspen in all blocks. While butt splitting was not an issue when felling aspen for an oriented strand board plant, it was for conifer sawlogs. As a result, the contractor hand-felled all conifers on the control and Treatment 1 blocks. However, the mill allowed the contractor to mechanically fell the conifer on Treatment 2 to demonstrate the advantages of mechanically felling and bunching all stems.

Grapple skidders dragged the bunches of aspen and conifer to separate decks at the landings. At the landing, a bucking crew delimbed and bucked the aspen logs into 2.6-m lengths. The aspen bolts were hauled to the mill when a truck load had accumulated, or when the decking area became congested. Conifer stems were accumulated in landing decks and delimbed with the skidder's blade prior to hauling. Conifer stems were not hauled until after the field studies were completed.

Study Results

Following harvesting of the Drayton Valley site, research found that various methods protected 40%1 of the original understory on the control block, 42% on Treatment 1 and 61% on Treatment 2 (Table 3). Understory damage measured included those residuals that were destroyed to make skid trails and landings, and residuals that were damaged by harvesting equipment or dragging stems. The main factors contributing toward understory protection were: the interest of the harvesting crew; the distribution of the understory relative to nonmerchantable species; and the presence of FERIC researchers during harvesting operations. A detailed description of study results and observations for each area follows. Table 3 summarizes understory stand damage.

Control. The control area was harvested in a manner where understory was protected rather than ignored, and probably reflected a modified Treatment 1 block rather than a typical conventionally logged area. This occurred because the crew were very enthusiastic and wanted to demonstrate their ability to protect the understory without supervision. The dense clumps of advanced regeneration throughout the control block also assisted in preserving undamaged understory

Table 3. Drayton Valley Understory Damage: Summary (Brace 1989)[a]

Item	Control		Treatment 1		Treatment 2	
	Trees/ ha	%	Trees/ ha	%	Trees/ ha	%
All understory stems	569.4	100	404.9	100	311.8	100
Undamaged	226.1	40	170.6	42	189.0	61
Felling						
Injured	59.6	10	61.7	15	27.0	9
Destroyed	4.1	1	0.0	0	2.5	1
Total felling damage	63.7	11	61.7	15	29.5	9[b]
Skidding						
Injured	115.1	20	61.7	15	51.6	17
Destroyed	135.6	24	102.8	25	39.3	13
Total skidding damage	250.7	44	164.5	41[b]	90.9	29[b]
Total injured	174.7	30	123.4	30	78.6	25[b]
Total destroyed	139.7	25	102.8	25	41.8	13[b]
Harvested	28.8	5	8.2	2	2.5	1
Natural mortality	0.0	0	0.0	0	0.0	0
Blow down	0.0	0	0.0	0	0.0	0
Total injured + destroyed + harvested	343.2	60	234.4	58	122.9	39[b]

[a] Brace, L.G. 1989. Results of pre- and post-harvesting data collected by Forestry Canada, Northern Forestry Centre. Unpublished.
[b] Discrepancies in totals are due to rounding.

because it made random skidding difficult and compelled the skidders to use previous skid trails. As a result, the understory protection practices were rates as intermediate rather than low.

The way in which the understory was distributed throughout the control block also assisted in the preservation of undamaged residuals. Most of the understory was located in dense clumps or scattered among nonmerchantable birch trees where there were few, if any, merchantable aspen or conifer stems. This allowed the feller-buncher and skidders to work around understory clumps and to avoid the area with nonmerchantable stems. As a result, the understory within these locations was left undisturbed.

Results of the post-harvesting surveys (Table 3) indicate that 30% of the understory stems were injured by harvesting activity, 25% were destroyed, and 5% were harvested. The skidding phase injured 20% and destroyed 24% of the residuals, while felling injured 10% and destroyed 1% of the understory stems. Residuals were injured during felling when the buncher, or felling trees, brushed against the standing immature stems, or when the overmature aspen stems broke during felling and landed in the understory. Understory stems were destroyed when they were located on skid trails and were run over by the skidders. Residuals beside skid trails were injured or destroyed as the passing skidder, stems, or branches from the stems, dragged against them. Some understory stems were also injured and destroyed during skidding when operators broke off the limbs on the bunched aspen stems by backing the bunches into standing aspen trees. A number of marginally merchantable conifers were felled by hand because the contractor wanted to recover as much conifer wood as possible.

The feller-buncher, hand feller, and four grapple skidders produced 2873 m^3 during the control block study. Table 4 summarizes the felling and skidding production.

The feller-buncher produced 68.8 m^3 per operating hour, worked 11 hours per day and required 5.9 production shifts to produce 2554 m^3 of aspen. The feller-buncher felled 114 trees per PMH and required .53 minutes to fell a tree (Table 5). The felling work elements represented 83% of the work cycle, with time equally spent on the move-to-cut, position-cut-bunch, and move-to-bunch cycles. Travel to other work areas, mechanical delays, and nonmechanical delays represented 17% of the work cycle.

The four skidders averaged 12.4 m^3 per operating hour, worked an average 9.5 hours per shift and required 34.2 production shifts to skid 2873 m^3 of aspen and spruce to the landings. The skidders skidded seven turns per PMH and averaged three logs per turn (Table 6). Each turn averaged 9.23 minutes. Turn size was determined by the size of bunch produced by the feller-buncher. Skidding distance averaged 95 m, and ranged from 20 to 230 m (Table 6). Skidding elements represented 52% of the work cycle, decking 42%, and delays 5%. The high proportion of time spent decking was due to the time required to pile and align the logs on the main deck so the hand buckers could safely slash the long logs.

Both mechanical felling and skidding production was reduced as a result of mechanical delays during productive shifts. The extensive time spent on mechanical repairs reflected the older age of the equipment and the lack of spare parts available at the site. The feller-buncher required extensive repairs to its undercarriage, final drives, and hydraulic lines during felling of the control block. The skidders required repairs to reduce overheating, replace universal joints on drive shafts, and repair grapple assemblies.

*Table 4. **Drayton** Valley **Shift-Level** Studies: **Summary**.*

Item	Control		Treatment 1		Treatment 2	
	Mechanical Felling	Skidding	Mechanical Felling	Skidding	Mechanical Felling	Skidding
Volume of aspen (m^3)	2554	2554	3759	3859	2340	2340
Volume of conifer (m^3)	0	319	0	948	296	296
Total volume (m’)	**2 554**	**2 873**	**3 759**	**4 807**	**2 636**	**2 636**
Scheduling intensity						
Production shifts	5.9	34.2	11.1	50.1	13.0	39.5
Shifts with no production						
Weekends	1.0	2.0	5.0	19.0	3.0	15.0
Repairs, wait for parts	0.0	5.0	7.0	11.0	0.0	6.0
No operator	0.0	0.0	1.0	4.0	1.0	2.0
Working out of study area	0.0	4.0	**0.0**	**14.0**	0.0	13.0
Total	**6.9**	**45.2**	24.1	98.1	**17.0**	**75.5**
Total distribution for productive shifts (hours)						
operating hours	37.1	231.7	54.1	303.9	50.1	213.7
Delays						
Mechanical **(MDH)**	24.1	53.1	16.8	66.8	16.4	37.2
Nonmechanical **(NDH)**						
Operational	2.4	13.8	10.0	41.5	0.3	30.0
Personal	**1.2**	25.2	7.0	**33.5**	**4.9**	**13.0**
Scheduled machine hours **(SMH)**	**64.8**	**323.8**	**87.9**	445.7	71.7	293.9
Average shift length (h)	11.0	9.5	7.9	8.9	5.5	7.4
Operating hours per shift	6.3	6.8	4.9	6.1	3.9	5.4
m^3 per operating hour	68.8	12.4	69.5	15.8	52.6	123
m^3 per **SMH**	39.4	8.9	42.8	10.8	36.8	9.0
Availability **(%)**	63	84	81	85	77	87
Machine utilization **(%)**	57	72	62	68	70	73

The following were also required to complete harvesting on the control block:

- The contract supervisor spent two **mandays** looking over the block and discussing the harvesting prescription with the contractor.
- A bulldozer spent **53.4** operating hours on the block constructing log-hauling roads, clearing landings, and clearing mud from truck roads after rain storms.
- One hand feller spent **27.5** operating hours felling 319 m^3 of conifer stems.
- **5-6 buckermen** spent a total of **36 mandays** cutting aspen into 2.6-m lengths.
- **The** contract supervisor spent one manday on the block supervising the harvesting operation.

The harvesting cost for the control block was $16.80 per m^3 in total (Table **7).** Skidding represented **53%** of the cost, felling **16%**, manual slashing **16%**, road and landing construction **12%**, and preharvest organization and **on-site** supervision **3%**.

Table 5. Drayton Valley Work Sampling - Felling and Bunching: Summary

Item	Control No.	Control %	Treatment 1 No.	Treatment 1 %	Treatment 2 No.	Treatment 2 %
No. of trees felled						
Aspen	811	100	1127	100	1253	87
co-tier		0		0	183	13
Total no. of trees felled	811	100	1 127	100	1 436	100
Summary of felling cycle element times	min	%	min	%	min	%
Move-to-cut	0.15	28.5	0.2s	35.9	0.16	31.5
Position-cut-bunch	0.15	27.8	0.12	17.1	0.10	19.4
Move-to-bunch	0.14	27.1	0.16	23.1	0.16	32.5
Process	n/a	n/a	n/a	n/a	n/a	n/a
Move-to-process	n/a	n/a	n/a	n/a	n/a	n/a
Move log	0.00	0.0	0.03	4.3	0.00	1.0
General felling	0.44	83.4	0.55 [a]	80.5 [a]	0.42	84.4
Travel	0.02	4.0	0.05	6.9	0.02	4.3
Brush	0.00	0.0	0.00	0.0	0.00	0.0
Delays <15 min						
Mechanical	0.03	6.5	0.01	0.9	0.01	2.8
Operational	0.01	2.1	0.04	5.7	0.03	5.9
Personal	0.02	4.0	0.04	6.1	0.01	2.6
Time per cycle	0.53 [a]	100.0	0.69	100.0 [a]	0.50=	100.0
Trees felled per PMH	114		87		119	
Total sampling time (h)	7.1		12.9		12.1	

[a] Discrepancies in totals due to rounding.

Treatment 1. Nearly the same amount of understory was left on Treatment 1 (Table 3) as was left on the control block even though this block was harvested using a designated skid-trail layout and the crew were to spend more effort on understory protection. This was a result of the continued interest of the crew in the project, and the way the understory was distributed throughout the block. Compared to the control block, Treatment 1 understory was less dense and more uniformly distributed.

The degree of understory protection was rated as intermediate because the crew were responsible for their own supervision and used their own judgement to locate secondary skid trails.

Results of the post-harvesting surveys (Table 3) indicate that 30% of understory stems were injured by harvesting activity and 25% were destroyed, the same as for the control block (Figure 4). Two percent of the understory stems were harvested on Treatment 1 block compared to 5% on the control area. Felling injured 15% of the Treatment 1 understory stems, 5% more than on the control block because more timber was hand-felled. Hand-felled trees brushed against understory trees during felling because their felling direction could not be controlled, as would be the case with a feller-buncher. Skidding injured 15% understory or 5% less than that injured in the control block. This reduction occurred because bunches were skidded along designated skid trails that were wide enough to prevent extensive darnage to trailside residual trees, and operators did not cut through the understory. The proportion of understory destroyed by felling and skidding remained the same (25%) for both Treatment 1 and the control block.

Table 6. Drayton Valley Work Sampling - Skidding: Summary

Item	Control No.	Control %	Treatment 1 No.	Treatment 1 %	Treatment 2 No.	Treatment 2 %
Number of logs skidded						
Aspen	569	74	1109	98	1045	82
Conifer	200	26	o	2	248	19
Total no. of logs skidded	769	100	1 109	100	1 293	100 [a]
Total no. of turns	253		275		275	
Average no. of logs per turn	3.0		4.0		4.7	
Travel distances (one-way)						
Maximum (m)	230		320		270	
Average (m)	95		130		130	
Minimum (m)	20		30		30	

Summary of skidding cycle element times	Control min	Control %	Treatment 1 min	Treatment 1 %	Treatment 2 min	Treatment 2 %
Skidding						
Travel empty	1.43	15.5	1.52	14.8	1.39	12.0
Position-and-load	1.54	16.7	1.38	13.5	1.39	12.0
Travel loaded	1.87	20.3	1.94	18.9	1.51	13.0
Total skidding	4.84	52.3 [a]	4.84	47.0 [a]	4.29	37.0
Decking						
Pull-in, delimb-and-pile	3.69	40.0	4.03	39.3	4.96	42.8
Clean landing	0.23	2.4	0.41	4.0	0.75	6.5
Delays less than 15 min						
Mechanical	0.10	1.1	0.11	1.1	0.24	2.1
Operational	0.28	3.0	0.78	7.6	1.09	9.4
Personal	0.10	1.1	0.09	0.9	0.27	2.3
Time per cycle	9.23 [a]	100.0 [a]	10.26	100.0 [a]	11.61 [a]	100.0 [a]
Logs per PMH	20		24		24	
Turns or loads per PMH	7		6		5	
Average travel rate (min/100 m)						
Empty	1.50		1.17		1.06	
Loaded	1.97		1.49		1.15	
Total sampling time (h)	38.9	100.0	47.0	100.0	53.2	100.0

[a] Discrepancies in totals due to rounding.

The feller-buncher, hand feller, and four grapple skidders produced 4807 m^3 during the Treatment 1 block study. Table 4 summarizes the felling and skidding production.

The feller-buncher produced 69.5 m^3 per operating hour, worked 7.9 hours per day and required 11.1 production shifts to produce 3759 m^3 of aspen. This was nearly the same felling production recorded for the control block. Mechanical felling was slightly more productive on Treatment 1 because less time was spent making mechanical repairs. However, the buncher operator had to load logging trucks during the night shift and, as a result, was not able to work a full shift on the buncher the next day. The feller-buncher felled 87 trees per PMH and required .69 minutes

*Table 7. Harvesting Costs for **Drayton** Valley: Summary*

Item	Control	Treatment 1	Treatment 2
Volume of aspen (m^3)	2554	3859	2340
Volume of conifer (m^3)	319	948	296
Total volume (m^3)	2873	4807	2636

	costs ($)	Control: No. of md[a] or OH[b]	Control: $/m³	Control: %	Treatment 1: No. of md[a] or OH[b]	Treatment 1: $/m³	Treatment 1: %	Treatment 2: No. of md[a] or OH[b]	Treatment 2: $/m³	Treatment 2: %
Plannin	$400/md[a]	2	0.28	2	3	0.25	2	2	0.30	2
Road construction & maintenance										
Bulldozer	$107.81/OH[b]	53.4	2.00	12	29.2	0.65	5	15.1	0.62	4
Harvest operations										
Mechanical felling	$110.55/OH	64.8	2.49	15	87.9	2.02	14	71.7	3.01	17
Manual felling	$27.00/OH	27.5	0.26	1	63.5	0.36	3	4.0	0.04	0
Skidding	$78.72/OH	323.8	8.87	53	445.7	7.30	53	293.9	8.78	50
Manual slashing	$220/md	36	2.76	16	67	3.07	22	52	4.34	25
Supervision	$400/md	1	0.14	1	2	0.17	1	2	0.30	2
Total			16.80	100		13.82	100		17.39	100

[a] Mandays.
[b] Operating hours.

Figure 4. Drayton Valley Treatment 1: Understory stems remaining after harvesting.

to fell a tree (Table 5). This 24% reduction in buncher production compared to the control block was due to the increased proportion of time spent moving to cut a tree. The buncher continually moved between the felling site (in the woods) and the bunching site (on the trails). The proportion of time spent on delays was similar (13%) to the control block.

The five skidders averaged 15.8 m^3 per operating hour, worked 8.9 hours per shift, and required 50.1 production shifts to skid 4807 m^3 of aspen and spruce to the landings (Table 4). Skidding production was reduced because wet weather prevented logging trucks from hauling and the log decks became too full. In addition, the skidders continued to experience similar mechanical delays as noted in the control block. The skidders skidded six turns per PMH, averaged four logs per turn, and each turn averaged 10.26 min (Table 6).

On Treatment 1 the overall skidding production increased by 20% compared to the control block despite the average time per turn increasing and the number of turns per PMH decreasing, because the number of logs per turn increased (Tables 4 and 6). Bunch size increased because the buncher was forced to accumulate as many stems as possible in one spot to avoid plugging the limited storage area provided by the trails. Although the average skidding distance of 130 m on Treatment 1 was significantly longer than for the control block, both empty and loaded travel speeds were faster than travel speeds on the control block. Travel speed increased because the skidder operators knew where the bunches were located along the trails and did not waste time searching for them.

The following were also required to complete harvesting the Treatment 1 block:

- The contract supervisor spent three mandays looking over the block and discussing the harvesting prescription with the contractor.
- A bulldozer spent 29.2 operating hours on the block constructing log-hauling roads, clearing landings, and clearing mud from truck roads after rain storms.
- One hand feller spent 63.5 operating hours felling 948 m^3 of conifer and 100 m^3 of aspen stems.
- 6-7 buckermen spent a total of 67 mandays cutting aspen into 2.6-m lengths.
- The contract supervisor spent two mandays on the block supervising the harvesting operation.

The cost to log the Treatment 1 block was \$13.81 per m^3 (Table 7). Skidding represented 53% of the total harvesting costs, manual slashing 22%, felling 1770, road and landing construction 5%, and pre-harvest organization and on-site supervision 3%. Harvesting costs on Treatment 1 decreased 18% compared to the control block. Skidding and felling costs decreased because these phases were more productive when harvesting Treatment 1 than the control block. Bulldozer costs decreased because this equipment was not used as often to maintain Treatment 1 landings and roads.

Treatment 2. Results of the post-harvesting surveys (Table 3) indicate that 61% of the understory stems were left undamaged after harvesting on Treatment 2. This resulted from harvesting a stand that had a relatively widely scattered understory, making it easier to avoid residuals during landing construction, felling, and skidding. The use of designated skid trails, a feller-buncher to fell all trees and fewer skidders also contributed to increased residual protection. For Treatment 2, fewer skidders were used to avoid interference between skidders.

The harvesting prescription for Treatment 2 determined that all bunches were to be rough delimbed and topped in the bush prior to skidding. However, only one of the three skidding teams delimbed or topped the bunches prior to skidding. The other slashing crews, working for the skidder subcontractors, found topping and delimbing in the bush required more effort than they were being paid for. The skidding subcontractors were unwilling to pay any additional bonus because no additional payment in turn was received from the primary contractor. The crew that did delimb and top in the bush worked for the contractor. This skidder operator, along with two landing buckers, spent 2-3 hours every morning delimbing bunches prior to skidding and decking.

The degree of understory protection was rated as intermediate because not all the contractors delimbed bunches before skidding. However, additional effort was spent pre-locating landings and skid trails when compared to Treatment 1.

On Treatment 2, 25% of the understory stems were injured and 13% were destroyed by harvesting operations, a significant reduction from the control block. Felling injured 9% of the understory, while skidding injured 17% and destroyed 13% of the residuals. While felling damage did not decrease significantly when compared to the control block, the use of the feller-buncher to place both conifer and aspen stems into bunches reduced the number of residuals destroyed during skidding. Only 1% of the residuals were harvested as care was taken to avoid felling any marginally merchantable tree if felling would damage healthy understory stems.

The feller-buncher, and three grapple skidders produced 2636 m^3 during the Treatment 2 block study (Table 4). Table 4 summarizes the felling and skidding production.

The feller-buncher produced 52.6 m^3 per operating hour, worked 5.5 hours per day and required 13 production shifts to fell all the aspen and conifer stems (Table 4). The feller-buncher felled 119 trees per PMH and required .50 minutes to fell a tree (Table 5). Feller-buncher production (m^3 per operating hour) was 24% less than on the control; this was attributed to a smaller stem size in Treatment 2 (Table 2) because the time required to fell a tree was similar on both blocks.

The three skidders averaged 12.3 m^3 per operating hour, worked 7.4 hours per shift, and required 39.5 production shifts to skid the bunches to the landings (Table 4). The skidders skidded five turns per PMH and averaged 4.7 logs per turn (Table 6). Each turn averaged 11.61 minutes, more than 2 minutes longer than for the control block because, although the time spent skidding decreased by .55 minutes, decking time increased by 1.27 minutes and delays increased 1.12 minutes. Decking time increased because one of the manual slashing crews delimbed bunched stems before the bunches reached the landing. Delays increased because more time was spent waiting for the manual slashing crews to delimb logs.

Despite the average turn taking more than two minutes longer on Treatment 2 than on the control block (Table 6), skidding production (m^3 per operating hour) remained the same (Table 4). This was a result of a larger turn size off-setting the fewer number of turns per PMH (Table 6) and smaller piece size (Table 2). The number of logs per bunch increased because the bunches were placed along the trails, where there was only limited space available.

Skidding distance on Treatment 2 averaged 130 m and ranged between 30 and 270 m (Table 6), which was greater than distances skidded on the control block. However, while skid distance increased more on Treatment 2 than on the control, both empty and loaded travel speeds decreased (Table 6). This occurred because the trails were well constructed, had few obstacles, and were aligned to the closest landing.

The following were also required to complete harvesting on the Treatment 2 block:

- The contract supervisor spent two mandays looking over the block and discussing the harvesting prescription with the contractor.

- A bulldozer spent 15.1 operating hours on the block constructing log-hauling roads and clearing landings.
- 4-5 buckermen spent a total of52 mandays rough delimbing and topping bunched stems before the stems were skidded, and cutting aspen into 2.6-m lengths.
- One hand feller spent four operating hours felling six conifers (9 m^3)that were too large for the buncher to sever.
- The contract supervisor spent two mandays on the block supervising the harvesting operation.

The cost to harvest the Treatment 2 block was $17.39 per m^3 (Table 7). Skidding costs represented 5090 of total harvesting costs, manual slashing 25%, felling 1890, preharvest organization and on-site supervision 470, and road and landing construction 3910. Harvest costs on Treatment 2 increased 4% compared to the control block, but were 26% greater than Treatment 1. Felling costs increased on Treatment 2 because the feller-buncher was less productive per scheduled machine hour. Skidding costs were similar to the control block, but were $1.48 greater than Treatment 1 because of differences in productivity per scheduled machine hours. Manual slashing costs increased significantly because of the time the slashing crew spent rough delimbing and topping stems prior to skidding. Bulldozer costs reflect the limited time the unit spent building landings and roads at Treatment 2.

Discussion

Observations made during the Drayton Valley case study indicated that felling and skidding alone were not the only cause of understory damage. These other causes were related to the disposal of landing debris, road construction, and road maintenance. Understory was damaged when landing debris (limbs and short lengths) was pushed aside to make room for log decks. Understory was also damaged during road construction and road maintenance when the bulldozer pushed soil overburden or mud into residuals. For the purposes of this report, these types of damage were attributed to the skidding category.

The overmature aspen stems in the Control and Treatment 1 blocks also contributed to understory damage. Understory was damaged when rotten upper sections and large branches broke off and fell into the understory. Additional understory damage occurred when these sections were either pushed aside or grappled by a skidder. This type of damage would not occur in a younger, thriftier mixedwood stand.

Limbing stems in the bush or away from the landing distributed more limbs over the cut block, with fewer being concentrated at the landing. This reduced the amount of debris on the landing that would have to be cleared away or disposed of later. However, aspen limbs that were left on the trail were pushed into trail-side understory, and caused damage to residuals as other bunches were dragged over the slash (Figure 5).

Skidding spruce stems was observed to cause damage to a number of understory stems mainly because the hand-felled spruce were not aligned to the desired skidding direction. Most of the time the aspen were felled in bunches with their butts pointed in the skid direction. Whereas the hand-felled spruce stems were not aligned to the landing and had to be turned around during skidding. When the spruce were swung around they knocked over understory which had been protected during other skidding functions. In addition, if merchantable spruce were felled within a dense understory clump, the skidder crushed a number of stems trying to recover this spruce. In some cases, the spruce were only marginally larger than the 25-cm dbh minimum requirement,

Figure 5. Tops from bush-delimbed bunches rode on top of underlying bunches during initial skidding, then fell off and were swept off the trail.

and immature spruce were damaged to recover minimal value stems. The spruce stems were also very bushy and their width, especially when bunched, exceeded the trail width.

The absence of an on-site supervisor or lack of proper briefing of crews influenced the Drayton Valley control, Treatment 1 and 2 study results in three ways. Initially, the crew did not immediately understand the purpose of the study. They thought that while the researchers monitored their performance on the Control block, they were expected to demonstrate their ability to protect understory stems from harvesting damage. Secondly, when harvesting the Treatment 1 and 2 areas, the crews became frustrated: they felt that the harvesting methods they were expected to use were causing their production (and, therefore, their income) to decline. There was no evidence, however, their productivity was affected duringthe study period. Thirdly, the feller-buncher operator had to spend more of his working time than normal searching for flagging that marked the boundaries and trails. This problem could easily be eliminated with an on-site supervisor who could have ensured that all boundaries and trails were clearly visible.

Except for some large aspen stems in both the control and Treatment 1 blocks, the JD755 had no difficulty working to the designated skid trail prescription and bringing the felled stems, from between the trails, back to the trail to make good-sized bunches. The JD755's narrow track width (1.6 m) ensured it could manoeuvre around residuals. However, the buncher was also 1 m narrower than the skidders. As a result, the trails were probably too narrow and trailside residuals were damaged or destroyed when the skidder wheels rubbed against them.

All stems on both Treatment 1 and 2 blocks were bunched in a shingle pattern (Figure 6) along the designated skid trails so the tops of one bunch were laid on the butts of the previous one. The narrow trail width prevented large bunches being made and resulted in the buncher making additional skid trails to deck stems. The skidders cleared the trails of stems after thebuncher had finished felling, After the trails were cleared, the buncher returned and reached into the stands on either side of the trail to recover more merchantable stems. These stems were again bunched on the trail in a shingle pattern.

Manual slashing of aspen stems limited skidding production on all Drayton Valley blocks because 40% of the skidding work cycle was spent either piling stems at the deck or waiting for the landing buckers to delimb and slash stems (Table 6). Manual slashing also required a large landing area because the skidders could not stack the logs very high.

Skidder production did increase on the designated skid trail layout despite a longer cycle time, mainly because of increased bunch size. Also, as the skidder operator became more familiar with the trail, he was able to travel faster, thereby reducing travel time and offsetting increased skid distances. The amount of turn time spent retrieving bunches also decreased because the skidder operator was easily able to spot bunches along the trail.

Although a relatively high percentage of understory stems were left undamaged after harvesting on the control, Treatment 1, and Treatment 2 blocks, their presence alone would not achieve stocking level required to establish a conifer land base. This was because the original understory was relatively dispersed and clumped, and only the control and Treatment 1 blocks had more than 400 stems per ha prior to harvesting. However, the remaining undamaged understory will be a supplemental growing stock in a regenerated deciduous stand, and will perpetuate a mixedwood land base. This will occur through growth of released understory, natural seeding-in of spruce under aspen, and acceptance of aspen seedling and sucker regeneration in areas of inadequate spruce stocking.

Figure 6. Bunches laid in a shingle pattern along skid trails.

HINTON CASE STUDY

Background

The main purpose of this case study was to document the differences in understory protection and harvesting costs that result when using the conventional roadside harvesting system combined with special practices to reduce understory damage, and the Scandinavian harvesting system (also known as the shortwood and cut-to-length system). The special practices incorporated into the conventional harvesting study included: extensive preharvest planning, on-site supervision during harvesting operations, delimbing and topping stems prior to skidding, and leaving rub posts beside the skid trails. The main difference between the two systems is the extent to which logs are processed when delivered to roadside. Roadside harvesting systems deliver tree-length stems to roadside landings where they must be delimbed. Scandinavian systems delimb and buck the stem at the felling site and deliver the manufactured logs to roadside.

The Hinton study area was located 25 km northeast of Hinton, Alberta in the Athabasca Working Circle of Weldwood of Canada Limited's Forest Management Agreement Area and within the province's Edson E6N Forest District (Figure 2). The study area (Figure 7) was divided into three harvesting blocks (a control, Treatment 1 and Treatment 2). The general silvicultural prescriptions prepared for this case study are summarized in Appendix V.

The density of white spruce understory between 2.5 and 14 m high at Hinton ranged from 793 to 1991 stems per ha, and was considered moderate to dense. Overall, the white spruce understory was distributed uniformly throughout the control and Treatment 2 areas. However, the understory was less dense and scattered on the eastern half of Treatment 1. Table 8 summarizes the preharvest stand conditions for each block.

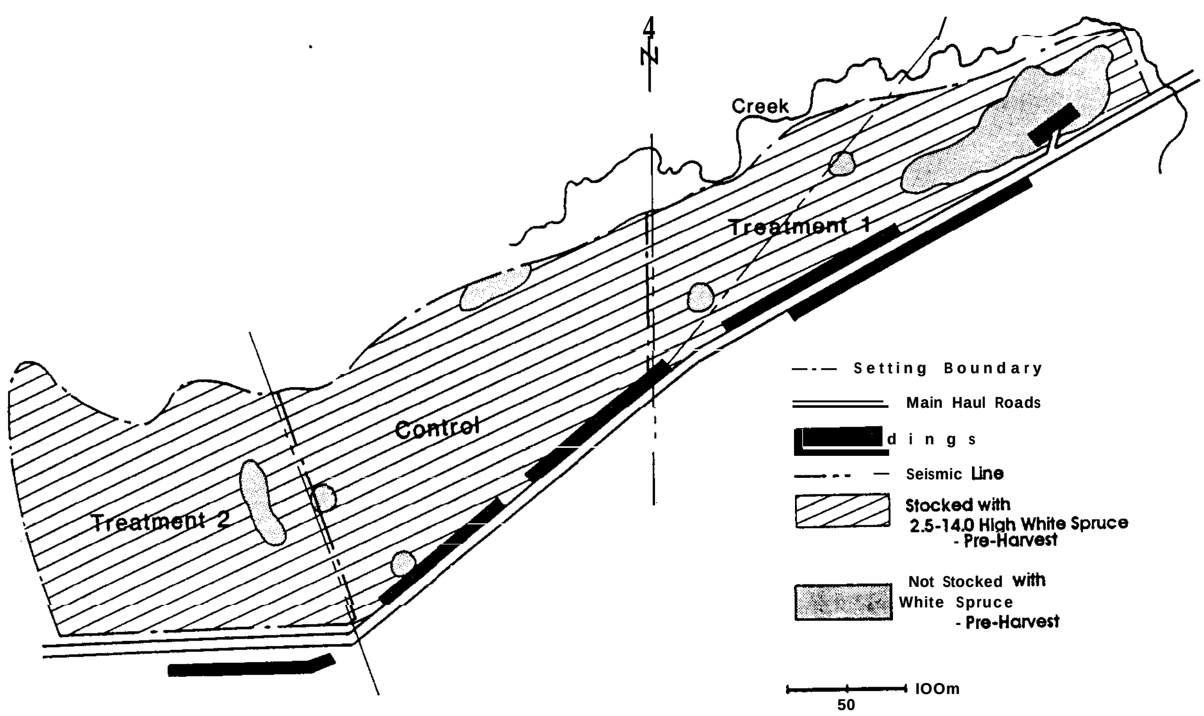

Figure **7.** *Block layout at Hinton study site.*

Conventional equipment felled and bunched trees at the control and Treatment 1 blocks, and a double-grip harvester felled and processed trees at Treatment 2. Two John Deere 693 feller-bunchers began felling the control area but were replaced by a Timberjack 2518 and a Timberjack 2520 (previously known as a Timbco 2518 and 2520) when mechanical problems reduced their productivity. All felling units were equipped with 52-cm shear heads. The Timberjack feller-bunchers completed felling the control and Treatment 1 areas. A pair of hand fellers also worked on the control and Treatment 1 blocks. A Rottne Snoken RP-860 double-grip harvester felled, delimbed and cut to length both aspen and conifer stems in Treatment 2. Stems too large for the harvester to handle were left standing.

A John Deere 648 and Caterpillar 518 grapple skidder dragged the long logs from the control and Treatment 1 areas to roadside decks. At Treatment 2, a Rottne Rapid six-wheel drive 10-tonne forwarder brought the short logs to roadside.

The tree-length aspen and conifer stems in the control and Treatment 1 areas were delimbed using a Denis stroke delimber mounted on a Komatsu PC200 carrier. All stems from Treatment 1 were processed by the stroke-delimber, although most stems had been manually delimbed and topped prior to skidding. This was necessary because not all the branches had been cut off flush with the stem. In addition, the stroke delimber topped the stems at the minimum diameter and restacked the decks to provide storage for all the logs. After all aspen stems from the control and Treatment 1 blocks were processed, they were slashed into 2.6-m lengths using a Hood portable slasher.

Study Results

Following harvesting of the Hinton site, research found that various methods preserved undamaged 16% of the original understory on the control block, 5290 on Treatment 1 and 30% on Treatment 2 (Table 9). Understory damage measured included those residuals that were destroyed to make skid trails and landings, and residuals that were darnaged by harvesting equipment or dragging stems. The main factor contributing to the variation in understory protection on both Treatment 1 and 2 blocks was equipment type. Ancillary factors contributing to the degree of understory protection on Treatment 1 were: the interest of the harvesting crew, the use of designated skid trails, the use of rub stumps beside skid trails, topping and limbing stems prior to skidding, and the presence of an on-site supervisor. A detailed description of the study results and observations follows. Table 9 summarizes understory damage.

Control. Only 16% of the understory was left undamaged following harvesting of the Hinton control block (Table 9) even though the harvesting crew were encouraged to protect understory residuals. However, no special practices were incorporated into the harvesting operation. The understory that was left was located midway from the road to the northerly boundary of the block. This occurred because there was a dense stand of understory within this area, and because there was less skidder traffic over the ground. Results of the post-harvesting surveys indicate that 30% of the understory stems were injured by harvesting activity, 52% were destroyed and 2% were harvested. Felling injured 6% and destroyed 290 of the understory stems, while the skidding phase injured 24% and destroyed 50% of the residuals. Most of the understory was knocked over and destroyed as skidders pulled the bunches to the nearest decking area.

Four feller-bunchers, two hand fellers, and two grapple skidders produced 2687 m^3 during the control block study. Table 10 summarizes the felling and skidding production.

Table 9. Hinton Understory Damage: Summary (Brace 1989)[a]

Item	Control		Treatment 1		Treatment 2	
	Trees/ ha	%	Trees/ ha	%	Trees/ ha	%
All understory stems	1744.0	100	793.3	100	1991.4	100
Undamaged	278.1	16	416.1	52	591.1	30
Felling						
Injured	105.6	6	101.3	13	480.6	24
Destroyed	41.0	2	6.5	1	69.0	3
Total felling damage	146.6	8	107.8	14	549.6	27
Skidding						
Injured	413.9	24	127.2	16	563.5	28
Destroyed	868.7	50	133.7	17	276.2	14
Total skidding damage	1282.6	74	260.9	33	839.7	42
Total injured	519.5	30	228.5	29	1044.1	52
Total destroyed	909.7	52	140.2	18	345.2	17
Harvested	36.6	2	8.6	1	11.0	1
Natursl mortality	0.0	0	0.0	0	2.8	0
Blow down	0.0	0	0.0	0	0.0	0
Total injured + destroyed + harvested	1465.9	84	377.3	48	1403.2	70

[a] Brace, L.G. 1989. Results of pre- and post-harvesting data collected by Forestry Canada, Northern Forestry Centre. Unpublished.

The feller-bunchers each produced 30.3 m^3 per OMH, worked 8.1 hours per day and required 17 production shifts to fell 2487 m^3 of aspen and conifer stems (Table 10). The feller-buncher felled 120 trees per PMH and required .50 min to fell a tree (Table 11). Felling work elements represented 75% of the work cycle, travel to other areas within the block 4%, and brushing 7%. Delays represented 15% of the work cycle.

The two hand fellers each worked four eight-hour days to fell 200 m^3 of oversized spruce.

The two skidders each produced 22.9 m^3 per operating hour, worked 7.6 hours per shift, and required 23.7 production shifts to skid the bunches to the landing (Table 10). The skidders skidded 12 turns per PMH and averaged 9.3 logs per turn (Table 12). Each turn averaged 5.21 min. Turn size was determined by the size of bunch produced by the feller-buncher. Skidding distance averaged 100 m and ranged between 20 and 350 m. Skidding elements represented 80% of the work cycle, decking 15%, and delays 570.

Mechanical delays, such as repairs to the hydraulic system, undercarriages, and engines, and nonmechanical delays reduced the felling time available to the bunchers. Hand fellers spent a considerable portion of their time waiting to cut the oversized trees or walking to them. Skidding production was also reduced because of mechanical repairs. However, skidding production was mainly reduced because the skidders had to wait for the bunchers to fell trees or because the operators were absent.

Table 10. Hinton Shift-Level Studies: Summary

Item	Control[a]		Treatment 1[a]		Treatment 2[b]	
	Mechanical Felling	Skidding	Mechanical Felling	Skidding	Felling & Processing	Forwarding
Volume of aspen (m^3)	1832		2050		1 450	
Volume of conifer (m^3)	855		0		600	
Total volume (m’)	2 687		2 050		2 050	
Scheduling intensity						
Production shifts	17.0	23.7	15.0	12.3	24.0	24.0
Shifts with no production:						
Weekends	4.0	8.0	8.0	4.0	8.0	8.0
Repairs, wait for parts	-					
No operator	-					
Working out of study area	-	3.0	-	-	-	
Total	21.0	34.7	23.0	16.3	32.0	32.0
Time distribution for productive shifts (h)						
Operating hours	88.6	117.2	85.8	75.4	192.5	195.4
Delays:						
Mechanical (MDH)	26.6	15.4	12.2	8.1	38.1	34.7
Nonmechanical (NDH)						
Operational	8.4	27.9	1.8	1.1	6.0	6.6
Personal	13.8	20.7	11.6	11.8	12.3	11.1
Scheduled machine hours (SMH)	137.4	181.2	111.4	96.4	248.9	247.8
Average shift length (h)	8.1	7.6	7.4	7.8	10.4	10.3
Operating hours per shift	5.2	4.9	5.7	6.1	8.0	8.1
m^3 per operating hour	30.3	22.9	23.9	27.2	10.7	10.5
m^3 per SMH	19.6	14.8	18.4	21.3	8.2	8.3
Availability (%)	81	92	89	92	85	86
Machine utilization (%)	64	65	77	78	77	79

[a] Production is based on tree-length stems skidded to roadside decks for delimbing.
[b] Production is based on stems being delimbed and cut to length at the felling site, and then forwarded to roadside decks.

The following were also required to complete harvesting on the control block:

- The contractor supervisor spent two mandays mapping and laying out the block, and preparing for the arrival of harvesting equipment.
- Two hand fellers spent 64 operating hours felling oversized conifers and assisting the feller-bunchers.
- A stroke delimber spent 69.0 operating hours delimbing all the aspen and conifer stems.
- A portable slasher spent 69.0 operating hours cutting the tree-length aspen into 2.6-m lengths.
- The contract supervisor spent three mandays supervising harvesting operations on the block.

The harvesting cost for the control block was $14.77 per m^3 (Table 13). Mechanical felling represented 33% of the cost, skidding 31%, mechanical delimbing and slashing 27%, preharvest planning and on-site supervision 5%, and hand felling 4%.

*Table 11. **Hinton** Work Sampling - Felling, Bunching and Felling, Processing: Summary*

Item	Control[a]		Treatment 1[a]		Treatment 2[b]	
	No.	%	No.	%	No.	%
No. of trees felled, or felled and processed						
Aspen	820	76	1317	99	355	86
conifer	264	24	11	1	60	14
Total no. of trees felled, or felled and processed	1 084	100	1.	100	415	100
Summary of felling cycle element times	min	%	min	%	rnin	%
Move-to-cut	0.11	22.3	0.16	27.5	0.24	12.8
Position-cut-bunch	0.19	38.4	0.22	38.9	0.47	24.7
Move-to-bunch	0.07	13.3	0.08	13.8	n/a	n/a
Process	n/a	n/a	n/a	n/a	0.93	49.2
Move-to-process	n/a	n/a	n/a	n/a	0.07	3.7
Move log	0.00	0.6	0.01	1.2	0.00	0.0
General felling	0.37	74.5[c]	0.47	81.4	1.71	90.4
Travel	0.02	4.1	0.03	5.6	0.00	0.0
Brush	0.03	6.8	0.01	2.1	0.03	1.5
Delays <15 min						
Mechanical	0.01	2.2	0.00	0.3	0.10	5.1
Operational	0.01	2.8	0.06	10.2	0.01	0.4
Pers	0.05	9.6	0.00	0.4	0.05	2.6
Time per cycle	0.50[c]	100.0	0.57	100.0	1.89[c]	100.0
Trees felled per PMH	120		104		32	
Total sampling time (h)	9.0		12.7		13.1	

[a] Production is based on tree-length stems skidded to roadside decks for delimbing.
[b] Production is based on stems being delimbed and cut to length at the felling site, and then forwarded to roadside decks.
[c] Discrepancies in totala are due to rounding.

Treatment 1. More than three times as many understory stems remained undamaged on Treatment 1 than on the control block (Table 9). This was a result of the crew's interest in the study, the use of designated skid trails, rub stumps being left beside the skid trails, topping and delimbing stems prior to skidding, and the presence of an on-site supervisor during most of the harvesting activity. The degree of understory protection was rated as high.

Results of post-harvesting surveys (Table 9) indicate that 52% of the original understory residuals were left undamaged on the Hinton Treatment 1 block (Figure 8). Of the residuals that were damaged, harvesting activities injured 29% of the stems and destroyed 18%, while 1% of the understory residuals were harvested. Felling activities injured 13% of the stems and destroyed 1%, while skidding activities injured 16% and destroyed 17%. Observations suggest damage occurred for a number of reasons, such as: when the skid trails were felled, as the feller-buncher tracks and head brushed against the residuals as the feller-buncher tracks were turned, as stems were bunched amongst understory residuals, as stems were dragged from amongst understory or along the trail, and as bunches were skidded around corners.

*Table 12. **Hinton** Work Sampling - Skidding and Forwarding: Summary*

Item	Control[a]		Treatment 1[a]		Treatment 2[b]	
	No.	%	No.	%	No.	%
No. of logs skidded or forwarded						
Aspen	1456	92	889	84	1182	94
conifer	131	8	164	16	70	6
Total no. of logs skidded or forwarded	**1 587**	**100**	m	**100**	**1 252**	**100**
Total no. of turns or loads	171		127		**13**	
Average no. of logs/turn or logs/load	9.3		8.3		**96.3**	
Travel distances (one-way)						
Maximum (m)	350		310		425	
Average (m)	100		190		250	
Minimum (m)	20		30		125	
Summary of skidding or forwarding cycle element times	**min**	%	**min**	%	**min**	%
Skidding or forwarding						
Travel empty	1.67	32.1	1.75	28.9	7.92	18.1
Position and load	1.09	21.0	1.35	22.2	19.92	45.6
Travel loaded	**1.40**	26.9	1.83	**30.2**	6.38	**14.6**
Total skidding or forwarding	4.16	**80.0**	**4.93**	81.3	**34.22**	78.3
Decking						
Pull-in, **delimb** and pile	0.80	15.2	0.95	15.7	6.38	16.0
Delays less thsn 15 **min**						
Mechanical	0.06	1.1	0.00	0.0	0.06	0.1
Operational	0.15	2.9	0.06	0.9	0.00	0.0
Personal	**0.04**	**0.8**	**0.13**	**2.1**	2.38	5.5
Time per cycle	**5.21**	100.0	**6.07**	100.0	**43.04**	100.0[c]
Logs per PMH	107		82		132	
Turns or loads per PMH	12		10		1	
Average travel rate **(min/100** m)						
Empty	1.67		0.92		3.17	
Loaded	1.40		0.96		2.55	
Total sampling time (h)	14.9		12.8		9.5	

[a] Production is based on tree-length stems skidded to roadside decks for **delimbing**.
b **Production is based on stems being delimbed** and cut to length at the felling site, and then forwarded **to roadside decks**.
[c] Discrepancy in total due to rounding.

Rub stumps (aspen stumps 1-1.5 m **tall**) left beside the skid trails, combined with rough **delimbing** and topping of the bunched stems prior to skidding, were observed to reduce **understory** damage related to skidding. The rub stumps protected **trailside** residuals from being injured by dragged bunches, and were especially effective at inside comers (Figure 9). Removing tops and branches on the bunched stems reduced the overall width of the bunch and eliminated damage caused to **trailside** residuals. Some bunches were felled off the trail and into **understory** stands and had to be dragged out of the stand onto the trail; in this case, rough **delimbing** and topping also contributed to reducing skidding damage to residuals.

*Table 13. **Hinton** Case Study Costs: Summary*

Item	Control[a]	Treatment 1[a]	Treatment 2[b]
Volume of aspen (m^3)	1832	2050	1450
Volume of conifer (m^3)	855		600
Total volume (m^3)	2 687	2 050	2 050

	costs ($)	No. of md[c] or OH[d]	$/m³	%	No. of md[c] or OH	$/m³	%	No. of md[c] or OH	$/m³	%
Preharvest										
Pfarming	$400/md[c]	2	0.30	2	10	1.95	11	3	0.59	2
Road construction & maintenance										
Bulldozer	$107.81/OH[d]				16	0.84	5		-	-
Harvest operations										
Mechanical felling	$96.43/OH	137.4	4.93	33	111.4	5.24	28		.	.
Manual felling	$27.00/OH	64	0.64	4	80	1.05	6	16	0.21	1
Harvester	.$ 103.28/OH							248.8	12.53	56
skidding	$68.13/OH	181.2	4.59	31	96.4	3.20	17			
Forwarder	.$74.491OH							247.8	9.00	40
Mechanical delimbing	$95.18/OH	69	2.44	17	49	2.28	12		-	-
Mechanical slashing	$55.00/OH	69	1.41	10	57	1.53	8		-	-
Supervision	$400/md	3	0.45	3	12	2.34	13	1	0.20	1
Total			14.77	100		18.44	100		22.53	100[e]

[a] Production is based on tree-length stems skidded to roadside decks for delimbing.
[b] Production is based on stems being delimbed and cut to length at the felling site, and then forwarded to roadside decks.
[c] Mandays.
[d] Operating hours.
[e] Discrepancies in totala are due to rounding.

*Figure 8. **Hinton's** Treatment 1: Understory stems remaining after harvesting.*

Figure 9. Rub stumps at inside corners protected adjunct understory from being damaged by dragging stems.

Understory damage was also reduced because the Timberjack 2518 and 2520 feller-bunchers were well suited to working amongst understory residuals. However, their overall width (one unit was 2.8 m and the second unit was 3.4 m wide) was more than the grapple skidders' overall width (one unit was 1.9 m and the second unit was 2.5 m). Therefore, wide skid trails were required. The Timberjacks had no overhanging counterweight and the boom, stick, and felling head could be pulled close to the centre of the machine. As a result, the Timberjack could rotate its upper works (including a severed stem) within the radius of the track width. The Timberjack 2500 series high cab position also afforded a clear view above the advanced regeneration. This complement of feller-buncher and grapple skidders, combined with skidding along designated skid trails, left stands of relatively undamaged understory in islands between skid trails.

The on-site supervisor assisted in reducing understory damage by ensuring the main trails and spurs were pre-located and flagged prior to felling. This ensured that all areas between the trails could be accessed by the feller-bunchers, that trails were spaced as far apart as possible, and the skidders could work efficiently. The on-site supervisor began layout by locating a main trail that accessed the far side of the block (from the road). He then began locating trails 15-20 m apart on a small area. As the buncher operators became familiar with the work pattern, and as the on-site supervisor observed their performance, he laid out more trails using the additional information. As often as possible, the trail ends were joined onto other trails and not dead-ended. This provided skidder access from both directions and the skid-trail pattern became a series of expanding concentric circular segments.

Alongside the main trails the on-site supervisor also marked aspen trees that were to be used as rub stumps to protect trailside residuals. Rub stumps were selected mainly at the inside of trail turns, and at trail junctions.

The two feller-bunchers and two grapple skidders produced 2,050 m^3 during the Treatment 1 study. Hand fellers did not fell any trees, but were used only to sever tops and rough delimb bunched stems. Table 10 summarizes the felling and skidding production.

The two feller-bunchers each produced 23.9 m^3 per operating hour, worked 7.4 hours per day and required 15 production shifts to fell all the aspen and conifer stems (Table 10). This was a 20% decrease in felling production compared to the control block probably because of an increased piece size. This was concluded because skidder productivity on a log-per-PMH basis decreased on Treatment 1, when compared to skidding on the control block. The feller-bunchers felled 104 trees per PMH on Treatment 1 and required .57 minutes to fell a tree (Table 11). This 13% reduction in buncher production was due to the increased amount of time spent on the move-to-cut and position-cut-bunch elements of the felling cycle in which the buncher spent additional time avoiding standing residuals.

On Treatment 1, felling was completed in a multi-pass process. During the first pass, the main skid trails were felled, then secondary trails off these main access trails were felled. The bunchers would start at the middle of open-ended trails or at the end of dead-end trails. Beginning at the middle allowed the skidders to access logs from the trail before the complete trail was felled. After a trail was felled, the skidders would clear away the bunches, allowing the buncher to return and fell the trees between trails in the final pass.

The two grapple skidders each averaged 27.2 m^3 per operating hour, worked 7.8 hours per shift and required 12.3 production shifts to skid the Treatment 1 timber to the landing (Table 10). Skidding production increased 18% when compared to the control block. The number of logs skidded per PMH on Treatment 1 was 82, or 2490 less than the control block. This decrease occurred because the number of turns per PMH and the number of logs per turn were less than on the control, and more time was spent skidding and decking turns. Skidding time increased because the average skid distance on Treatment 1 was nearly twice the control block's skid distance. However, when the travel time was pro-rated to a 100-m distance, Treatment 1 skidder speed in both directions was faster (Table 12). This was because the skid trails had few obstacles and because the skidder operators did not have to search the block looking for the next bunch to skid.

No major delays occurred during the Treatment 1 study. The delays that did occur were related to routine servicing and fuelling, repairs to the hydraulic systems, and operator rest breaks. The presence of the on-site supervisor appeared to reduce the length of delays as he would immediately request mechanical support when a repair was necessary, or discuss operational procedures with the crew on a regular basis.

The following were also required to complete harvesting on Treatment 1:

- The logging supervisor spent 10 mandays looking over the block, locating and flagging the main skid trails, and preparing for the arrival of harvesting equipment.
- Two hand fellers spent ten 8-hem days rough delimbing and topping bunched aspen and spruce stems.
- A bulldozer spent 16 operating hours constructing a spur road and a landing.
- A stroke delimber spent 49 operating hours delimbing and cutting-to-length all stems because

the hand fellers did not cut all the limbs flush with the stem.

- A mechanical slasher spent 57 operating hours cutting the tree-length aspen into 2.6-m lengths.
- Anon-site supervisor spent 12mandays supervising harvesting operations on the block.

The cost to harvest Hinton Treatment 1 was \$18.44 per m^3 (Table 13). Mechanical felling represented 28% of the harvesting costs, pre-harvest organization and on-site supervision 24%, mechanical delimbing and slashing 20%, skidding 17%, hand felling 6%, and road and landing construction 570. Hinton Treatment 1 harvesting costs were 25% more than harvesting costs for the control block mainly because of increases attributed to preharvesting layout and on-site supervision (\$3.54 per m^3), bulldozer rental (\$.84 per m^3), and increased felling costs (\$.72 per m^3). However, part of these increases were offset by decreased skidding costs (\$1.39 per m^3).

Treatment 2. Compared to the Hinton Treatment 1 block, significantly more understory was left damaged on the Hinton Treatment 2 block (Table 9). This difference was attributed to the type of equipment used to harvest each block. Treatment 2 was harvested using Scandinavian equipment (a harvester and a forwarder) and Treatment 1 was harvested using feller-bunchers and grapple skidders.

Results of the post-harvesting surveys (Table 9) indicate that 30% of understory residuals were left undamaged after harvesting on Treatment 2, 52% were injured, 17% were destroyed, and 1% were harvested. Felling and processing injured 24% and destroyed 3910 of the understory, and forwarding injured 28% and destroyed 14%. That a greater proportion of residuals being injured than on Treatment 1 was attributed to the work cycle of the double-grip harvester and forwarder. The double-grip harvester could not carry a severed stem to a clear bunching location although it could direct the stem to fell in a designated location (Figure 10). After felling, the head and

Figure 10. Single-grip harvester felling aspen stem.

boom dragged the stem to the processor mounted on the unit's back. The processor delimbed and cut the stem into the designated lengths. As the stems and their branches were dragged into the processor, they scraped, knocked over, or broke standing residuals. The forwarder injured residuals when its grapple or log load brushed against trail-side understory. However, Forestry Canada admitted some difficulty in accurately determining whether the harvester or forwarder had caused trail-side injuries. As a result, some of the injuries attributed to forwarding may have actually been caused by the harvester.

The double-grip harvester and forwarder had similar production capacities and each required the same length of time to harvest the 2050 m^3 of timber on Treatment 2 block. Table 10 summarizes the harvester and forwarder production.

Production for both the harvester and forwarder averaged between 8.2 and 8,3 m^3 per operating hour. The harvester averaged 10.4 hours per shift, the forwarder averaged 10.3 hours per shift, and both required 24 production shifts to fell and transport all the aspen and conifer stems. The shift length was longer than Treatment 1 because the Scandinavian equipment was operated by a contract crew that worked longer shifts than the Weldwood crew. The significant reduction in production per operating hour for the Scandinavian equipment, when compared to the equipment operating on the control block, was related to the different operating techniques of the two systems: the conventional system delivered tree-length stems to roadside where they were delimbed, whereas the Scandinavian equipment delimbed and cut the stems into log lengths at the felling site and forwarded the logs to roadside decks. No major delays reduced production. The mechanical delays that did occur were mainly associated with routine servicing, repairs to hydraulic lines and carrier brakes, and replacement of saws and bars on the felling or processor head.

The double-grip harvester felled and processed 32 logs per operating hour and required 1.89 minutes to fell and process each stem (Table 11). Observations made when monitoring the harvester indicated felling and processing time increased as trees got taller. The factors causing the increase were: more logs were cut from each stem, taller trees had larger diameters that took longer to cut through, and longer logs became heavier and more awkward to place in the processing head. Another factor that decreased harvester productivity was the density of understory stems. As understory density increased, the harvester spent more time manoeuvring around stems, or the felling head became hung up on the residuals while being placed around merchantable stems.

The forwarder averaged one load per PMH and carried 132 shortwood logs to roadside on each trip. The average travel distance from the decking area to the loading point was 250 m and ranged between 125 and 425 m. Observations made when monitoring the forwarding phase indicated forwarder productivity increased under the following conditions: as log length and diameter increased fewer logs were required to make-up a load; when understory was scattered, the grapple could pick up logs without interference from residuals; the closer together the processed logs were piled in the bush, the less distance the forwarder had to travel to accumulate a load; and when travel speed was not slowed because of rough or narrow trails.

The double-grip harvester and forwarder were less than half as productive as the feller-buncher and grapple skidder in Treatment 1 because the work cycles of each pair were different (Table 11 and 12). The feller-buncher only severed a tree and placed it in a bunch, whereas the harvester felled, delimbed, and cut the stem into log lengths. The skidder grappled a bunch of logs and skidded it to roadside where the delimber and slasher processed each log. The forwarder retrieved the logs at the felling site, transported them to the decking area, and then off-loaded them.

The following were also required to complete harvesting on Treatment 2:

- Theon-site supervisor spent three mandays laying outthe block, and explaining the harvesting prescription to the contractor.
- The contractor spent two 8-hour shifts felling oversized conifers.
- Anon-site supervisor spent onemanday supervising harvesting operations on the block.

The cost to harvest the Hinton Treatment 2 block was \$22.53 per m^3 (Table 13), The felling-processing phase represented 56% of Treatment 2 harvesting costs, forwarding 40%, and preharvest organization and on-site supervision 3%. The Hinton Treatment 2 harvesting costs were greater than harvesting costs for the control and Treatment 1 blocks mainly because of the different type of equipment and associated capital costs. The higher cost to harvest Treatment 2 was a result of using equipment that had relatively low productivity. However, some monetary advantages of using the Scandinavian harvesting system were identified but not quantified. These advantages were:

- Slash from the limbing and processing phase was left in the bush and did not have to be piled and burned at roadside. Leaving the slash in the bush would reduce nutrient losses associated with removal, and would shade the ground, thereby impeding soil warming and suckering.
- The logs produced by the harvester could be fed directly into the debarker on the sawmill deck and did not have to be cut to length on the infeed deck.
- More wood was recovered from the stand because the harvester could process stems that would have been too small for conventional roadside harvesting equipment to handle.
- The logs could have been loaded directly onto logging trucks instead of being decked at roadside, thereby reducing loading costs.

Discussion

The feller-buncher operators felt frustrated when they first began felling Treatment 1 because they were trying to protect all the understory. They found it difficult to decide which stems could be bunched with the least damage to residual stems. In addition, the harvester operator found he could not see the base of the tree he wanted to cut when he worked amongst dense patches of understory in Treatment 2. The dense understory also reduced spacing between trails because the harvester could not pull the felled stems through the standing residuals. After about one week of work, the feller-buncher and harvester operators on the Hinton Treatment 1 and 2 blocks became more confident in their working patterns. However, even after two weeks, the operators found the work required more concentration than when they harvested without regard to protecting understory stems.

The presence of an on-site supervisor at the Treatment 1 and 2 blocks helped the operators determine which understory stems should be felled to aid skidding, and kept the equipment running smoothly. When equipment broke down, or repairs were needed, the on-site supervisor would call the company mechanical shop for assistance, or would arrange for a replacement unit.

The substantial initial understory density differences between Treatment 1 (793 trees/ha) and Treatment 2 (1991 trees/ha) resulted in increased operating problems at Treatment 2. In addition, these more densely stocked stands were able to tolerate significant levels of understory damage during harvesting and still retain stocking. Damage of 48% at Treatment 1 resulted in 416 undamaged stems per ha and damage of 7090 in Treatment 2 resulted in 591 undamaged stems per ha.

The use of conventional and Swedish equipment to harvest mature timber and protect residuals located in a moderate-to-densely stocked immature stand resulted in two very different results but not a critical difference in post-harvest stocking. The use of feller-bunchers and grapple skidders, designated skid trails, and rub stumps, and pre-topping stems prior to skidding (Treatment 1) left a relatively undamaged understory that was located in islands between well-defined skid trails. The use of a double-grip harvester and forwarder working amongst dense understory (Treatment 2) resulted in a high proportion of the remaining residuals being injured (Table 9). It was also observed that skid trails created by the harvester and followed by the forwarder were almost inconspicuous.

BLUE RIDGE CASE STUDY

Background

The main purpose of this case study was to document the differences in understory protection and harvesting costs that result from using conventional roadside harvesting equipment combined with on-site supervision and special practices compared to Swedish harvesting systems. While the general harvesting prescription at Blue Ridge was similar to the Hinton case study, there are several differences between the two. First, the Blue Ridge case study blocks had a light-to-moderate stocking of understory stems. Second, the felling equipment used was slightly different. A more conventional feller-buncher was used on the control and Treatment 1 blocks, while a single-grip as well as a double-grip harvester was employed on Treatment 2. Finally, the supervision and work practices on the Treatment 1 and 2 blocks was different. The contract supervisor was on-site during harvesting of Treatment 1, while the crew supervised themselves at Treatment 2. Also, the Treatment 1 crew benefited from the operating techniques developed by the crews at Hinton and Drayton Valley. The Treatment 2 crew treated the harvesting more as a conventional block, with an intermediate level of understory protection. The Blue Ridge Treatment 2 thus served as the control to the Hinton Treatment 2 case study where care had been taken to protect the understory.

The Blue Ridge study area consisted of two sites located 25-35 km north of Blue Ridge, in the Whitecourt Forest District W6 unit of Alberta Energy Corporation's Forest Management Agreement (Figure 2). The larger area was divided into two blocks (a control and Treatment 1) and the smaller area was designated Treatment 2 (Figure 11). The silvicultural prescription prepared for this case study is summarized in Appendix V.

The density of white spruce understory between 2.5 and 14-m high at Blue Ridge ranged between 177 and 578 stems per ha, and was considered to be lightly to moderately stocked. Overall, the white spruce understory was uniformly distributed throughout the study areas, although the control block had considerably less. Table 14 summarizes the preharvest stand conditions for each area.

The aspen was generally sound in both the control and Treatment 1 blocks, and had approximately the same stem diameter and height as at the Hinton study site. Treatment 2 contained a large proportion of spruce stems between 22 and 30 cm at the stump, and fewer large conifers than at either the Drayton Valley or Hinton study sites.

The terrain at the Blue Ridge control and Treatment 1 blocks was flat and the ground was frozen during all the felling and skidding. The terrain at Treatment 2 was more difficult, with about 15% of the area located on slopes between 20 and 35%, and moist-to-wet soil conditions.

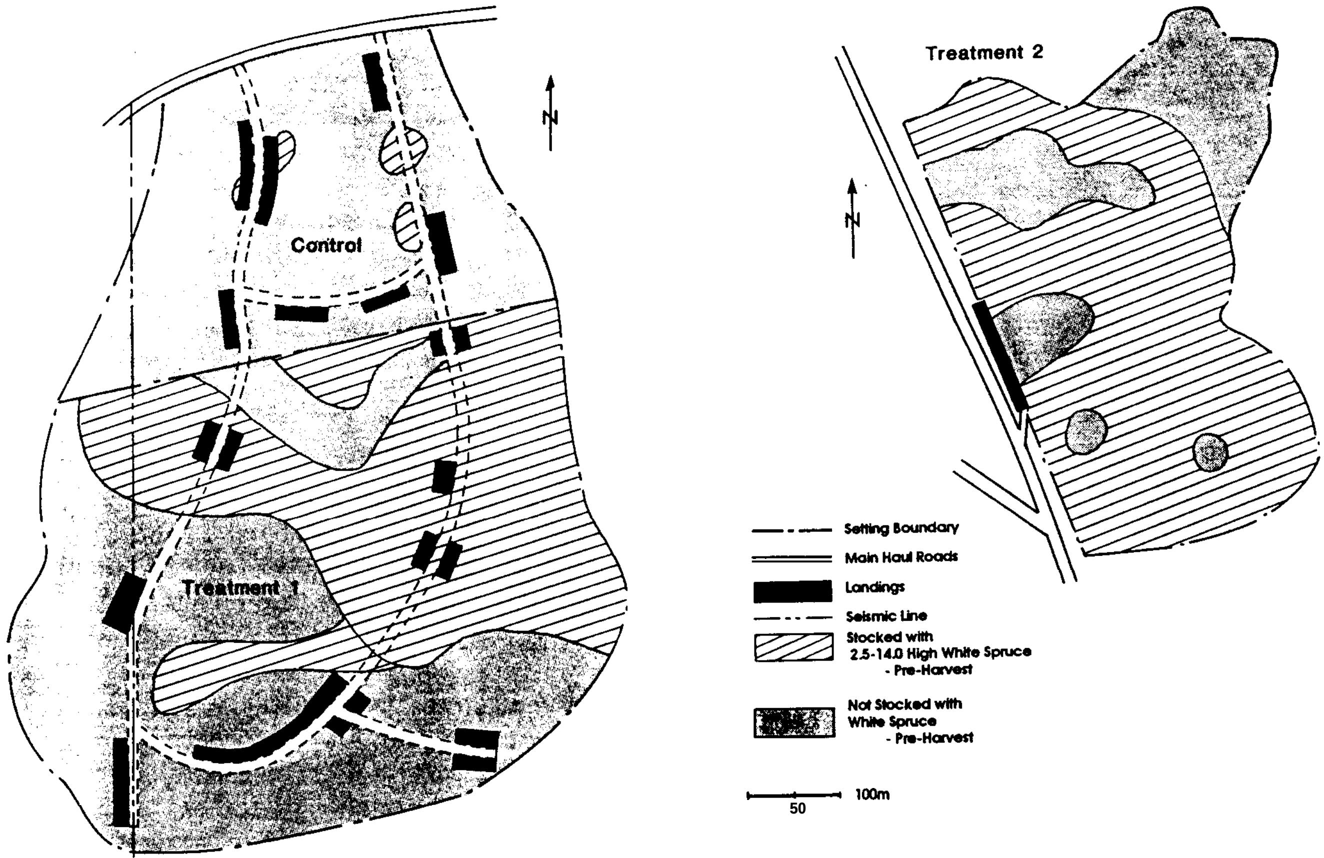

Figure 11. Block layout at Blue Ridge study site.

Table 14. Stand Conditions for Blue Ridge Case Study: Summary (Brace 1989)[a]

	Control	Treatment 1	Treatment 2
Area harvested (ha)	9.4	28.0	15.0
White spruce understory density (stems/ha) between 2.5-14.0 m height	177	428	578
Stand density (stems/ha)			
Aspen	438	322	938
Black poplar	37	142	156
White birch	14	3	81
White spruce (14+ m high)	109	98	65
Black spruce	0	0	14
Lodgepole pine	0	6	5
Total	598	571	1 259
Merchantable volume (m³/ha)			
Aspen	327	275	120
White spruce (14+ m high)	82	77	70
Black spruce	0	0	0
Lodgepole pine	0	13	3
Total merchantable volume	409	365	193
Nonmerchantable hardwood (m³/ha)	12	29	20
Merchantable volume per stem (m')			
Aspen	0.75	0.85	0.13
White spruce (14+ m high)	0.75	0.79	1.08
Black spruce	0	0	
Lodgepole pine	0	2.15	0.50

[a] Brace, L.G. 1989. Results of pre- and post-harvesting data collected by Forestry Canada, Norther Forestry Centre. Unpublished.

Preharvest planning and harvesting supervision on the control and Treatment 1 blocks were undertaken by Blue Ridge Lumber (1981) Ltd., and the blocks were harvested between March and May 1990. Preharvest planning and harvesting supervision on Treatment 2 was undertaken by Millar Western Industries Ltd., and the block was harvested during July and August 1989.

One loop and two spur roads were located and flagged throughout the control and Treatment 1 blocks to provide access to the landings. A proper road was not constructed until after the timber had been skidded to the decks because the logs could not be hauled until the summer hauling season. During harvesting, the proposed road location was used as a main skid trail. No haul roads were constructed into the Treatment 2 block because all logs could be decked beside the main road that ran along the western block boundary:

All aspen trees over 10-cm diameter, and all conifer over 14-cm diameter were harvested. The control and Treatment 1 blocks were harvested by a contractor for Blue Ridge Lumber (1981) Ltd. The crew was paid on an hourly basis when harvesting both the Control and Treatment 1 blocks. Treatment 2 was harvested by both Millar Western Industries Ltd. 's own equipment and crew, and the contractor's equipment and crew. The Treatment 2 crews were paid on a piece-rate basis.

The equipment used to harvest the control block consisted of conventional roadside harvesting equipment: one Timberjack 618 (previously known as the Koehring 618) feller-buncher equipped with a 46-cm diameter, high-speed, disc-saw felling head; two Timberjack grapple skidders (one TJ450 and a TJ480B); and one Denis stroke delimber mounted on a Komatsu PC200 carrier. The same equipment plus a Caterpillar 235C butt-and-top log loader was used to harvest the Treatment 1 block. Treatment 2 was harvested using Swedish equipment. A Rottne Snoken 860 RF-81 single-grip harvester, a Rottne Snoken RP860 double-grip harvester (both owned by Millar Western Industries Ltd.) felled and processed the stems. Two Rottne Rapid 10-tonne forwarders (one owned by Millar Western and one owned by a contractor) transported the processed logs to roadside decks. The double-grip harvester and forwarder were the same type of equipment as used to harvest Hinton Treatment 2.

All aspen logs from the Blue Ridge study sites were hauled 60 km to the Millar Western Industries Ltd. pulpmill at Whitecourt. Tree-length aspen logs were hauled from the control and Treatment-1 blocks, while 3.7-6 .1-metre (12-20 foot) lengths were hauled from Treatment 2. Conifer logs were hauled tree length from the Control and Treatment 1 study sites in 4.9-6 .1-metre (16-20 foot) lengths to the Blue Ridge Lumber (1981) Ltd. mill at Blue Ridge.

Study Results

Following harvesting of the Blue Ridge site, research found that harvesting activities damaged 98% of the original understory on the control block, 39% on Treatment 1, and 78% on Treatment 2 (Table 15). Understory damage measured included those residuals that were destroyed to make skid trails and landings, and residuals that were damaged by harvesting equipment. As at Hinton, the main factor that contributed to the variation in understory damage between the Treatment 1 and 2 blocks at both Blue Ridge and Hinton, was the type of equipment used on each block. Factors that contributed to the degree of understory protection on Treatment 1 were: the interest of the harvesting crew, the use of designated skid trails, the use of rub stumps beside skid trails, topping and delimbing stems prior to skidding, and the presence of an on-site supervisor. A detailed description of the work, study results, and observations is presented below. Table 15 summarizes understory damage.

Table 15. Blue Ridge Understory Damage: Summary (Brace 1989)[a]

Item	Control		Treatment 1		Treatment 2	
	Trees/ha	%	Trees/ha	%	Trees/ha	%
All understory stems	176.8	100	428.1	100	578.1	100[b]
Undamaged	4.0	2	259.6	61	119.4	21
Felling						
Injured	0.0	0	34.5	8	172.0	30
Destroyed	18.1	10	1.4	0	16.7	3
Total felling damage	18.1	10	35.9	8	188.7	33
Skidding						
Injured	12.0	7	27.6	6	119.4	21
Destroyed	130.6	74	88.4	21	86.0	15
Total skidding damage	142.6	81	116.0	27	205.4	36
Total Injured	12.0	7	62.1	14	291.4	51
Total destroyed	148.7	84	89.8	21	102.7	18
Harvested	12.1	7	15.2	4	54.9	9
Natural mortality	0.0	0	0.0	0	0.0	0
Total injured + destroyed + harvested	172.8	98	167.1	39	449.0	78
Blow down	0.0	0	0.0	0	9.6	2

[a] Brace, L.G. 1989. Results of pre- and post-harvesting data collected by Forestry Canada, Northern Forestry Centre. Unpublished.
[b] Discrepancy in total due to rounding.

Control. Results of post-harvesting surveys (Table 15) indicate 2% of the understory stems on the Blue Ridge control block were left undamaged, 7% of the residuals were injured, 84% were destroyed and 7% were harvested. Felling activities destroyed 10% of the understory, while skidding activities injured 7% and destroyed 74%.

Three factors contributed to the high number of understory residuals being damaged during harvesting of the Blue Ridge control block. First, the crew paid no attention to understory protection during their harvesting activities. Second, the block had only a low density of understory prior to harvesting and these were quickly damaged by the feller-buncher during the felling cycle or by skidders as they dragged logs to the nearest landing. Finally, the feller-buncher harvested a number of the larger-diameter understory conifers because they were marginally acceptable to the mill.

The feller-buncher, two grapple skidders, and delimber produced 1835 m^3 of aspen and conifer during the control block study. Table 16 summarizes the felling and skidding production.

The feller-buncher produced 44.5 m^3 per operating hour, worked 9 hours per day and required 8.1 production shifts to fell all the aspen and conifer stems. During the study, the feller-buncher's availability was reduced when its pressure relief valve malfunctioned and required parts and special service expertise. The feller-buncher felled 119 trees per PMH and required .50 minutes to fell a tree (Table 17). The felling cycle represented 91% of total cycle time with the most time spent 'moving-to-cut' a stem and 'position-cut-bunch' elements because the trees were relatively uniformly distributed over the block.

Table 16. Blue Ridge Shift-Level Studies: Summary

Item	Control[a]			Treatment 1[a]			Treatment 2[b]	
	Mechanical falling	Skidding	Delimbing	Mechanical falling	Skidding	Delimbing	Falling & Pro	
Volume of aspen (m^3)		1 542			2 354		1 659	
Volume of conifer (m^3)		293			1 375		458	
Total volume (m^3)		1 835			3 729		2 117	
Scheduling intensity								
Production shifts	8.1	9.6	7.6	22.9	33.4	15.4	24.0	23.0
Shifts with no production:								
Weekends + holidays	[illegible].0	0.0	0.0	7.0	6.0	3.0	8.0	8.0
Repairs, wait for parts	[illegible].0	0.0	0.0	0.0	3.0	0.0	0.0	0.0
No operator	[illegible].0	0.0	0.0	3.0	0.0	0.0	0.0	4.0
Working out of study area	[illegible].0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	[illegible]1	9.6	7.6	32.9	42.4	18.4	32.0	35.0
Time distribution for productive shifts (h)								
Operating hours	41.2	75.8	60.0	175.3	286.3	121.2	227.8	209.8
Delays								
Mechanical (MDH)	40.2	3.1	8.4	32.1	20.8	10.6	36.2	21.4
Nonmechanical (NDH)								
Operational	0.6	1.2	1.8	15.5	10.9	10.7	1.1	8.0
Personal	1.0	0.9	3.4	2.5	13.2	5.3	17.5	11.2
Scheduled machine hours (SMH)	83.0	81.0	73.6	225.4	331.2	147.8	282.6	250.4
Average shift length (h)	9.0	8.5	9.8	9.9	9.9	9.5	11.8	10.9
Operating hours per shift	4.5	8.0	8.0	7.7	8.5	7.8	9.5	9.1
m^3 per operating hour	44.5	24.2	30.6	21.3	13.0	30.8	9.3	10.1
m^3 per SMH	22.1	22.7	24.9	16.5	11.3	25.2	7.5	8.5
Availability (%)	52	96	89	86	94	93	87	91
Machine utilization (%)	50	94	82	78	86	82	81	84

[a] Production is based on tree-length stems skidded to roadside decks for delimbing.
[b] Production is based on stems being delimbed and cut to length at the felling site, and then forwarded to roadside decks.

Table 17. Blue Ridge Work Sampling - Felling, Bunching and Felling, Processing: Summary

Item	Control[a] No.	Control[a] %	Treatment 1[a] No.	Treatment 1[a] %	Treatment 2[b] No.	Treatment 2[b] %
No. of trees felled, or felled and processed						
Aspen	2043	85	1085	77	646	89
Conifer	366	15	320	23	77	11
Total no. of trees felled, or felled and processed	2 409	100	1 405	100	723	100
Summary of felling cycle element times	min	%	min	%	min	%
Move-to-cut	0.09	18.1	0.15	20.2	0.09	8.8
Position-cut-bunch	0.30	59.9	0.32	44.2	0.32	31.4
Move-to-bunch	0.02	4.3	0.06	8.0	n/a	n/a
Process	n/a	n/a	n/a	n/a	0.41	40.1
Move-to-process	n/a	n/a	n/a	n/a	0.01	0.9
Move log	0.01	1.6	0.01	1.3	0.00	0.0
Brush	0.04	7.1	0.02	3.3	0.05	4.9
General felling	0.46	91.1[c]	0.56	76.9[c]	0.88	86.1
Travel	0.02	3.5	0.12	16.8	0.02	1.9
Delays <15 min						
Mechanical	0.00	0.4	0.00	0.5	0.11	10.3
Operational	0.02	4.9	0.03	4.5	0.01	0.7
Personal	0.00	0.1	0.01	1.3	0.01	1.1
Time per cycle	0.50	100.0[c]	0.72	100.0[c]	1.03	100.0[c]
Trees felled per PMH	119		82		59	
Total sampling time (h)	20.2	100.0	17.2	100.0	12.3	100.0

[a] Production is based on tree-length stems skidded to roadside decks for delimbing.
[b] Production is based on stems being delimbed and cut to length at the felling site, and then forwarded to roadside decks.
[c] Discrepancies in totals are due to rounding.

Feller-buncher production (m^3 per operating hour) at the Blue Ridge control block was 47% greater than production at the Hinton control block and 35% less than production at Drayton Valley control. Because all the feller-bunchers felled nearly the same number of trees per PMH, this difference in production was attributed to differences in the average tree size.

The two skidders each produced 24.2 m^3 per operating hour, worked an average of 8.5 hours per day and required 9.6 production shifts to skid the felled bunches to the landings (Table 16). During the study, the skidding phase lost three shifts when the grapple knuckle assembly broke on the TJ480B and parts had to be delivered from Edmonton. The skidders skidded 14 turns per PMH and averaged 4.8 logs per turn (Table 18). Each turn took 4.24 minutes. At the Blue Ridge control block, the skidding phase represented 76% of the overall skidding cycle while decking accounted for 22%. Skidding distance averaged 70 m and ranged between 10 and 140 m.

Skidding production (m^3 per operating hour) at Blue Ridge control was 6% higher than at the Hinton control and twice as much as recorded during the Drayton Valley control study. This difference in production occurred because of differences in cycle times, the number of logs per bunch, and the size of each log. The cycle time at Drayton Valley was nearly twice that at Blue Ridge because the Drayton Valley skidders spent more of their cycle time decking logs for manual slashing, and waiting for the buckermen to finish bucking the logs. Skidders at Hinton and Blue Ridge did not have to wait for buckermen, and decking time was relatively fast. The differing bunch sizes at the Hinton and Blue Ridge sites reflects the varying operating techniques used by the buncher operators because of equipment constraints. The Blue Ridge feller-buncher was not as well suited to traveling with a severed stem as the Hinton buncher. As a result, the Blue Ridge operator usually bunched stems at a location within the swing radius of his buncher. At Hinton, the feller-buncher operator could travel with a severed stem and increase the size of bunches that were located outside the swing radius of his machine.

Table 18. Blue Ridge Work Sampling - Skidding and Forwarding: Summary

Item	Control[a]		Treatment 1[a]		Treatment 2[b]	
	No.	%	No.	%	No.	%
No. of logs skidded or forward						
Aspen	1109	71	1237	98	1227	78
Spruce	462	29	25	2	350	22
Totrd no. of logs skidded or forwarded	1 571	100	1 262	100	1 577	100
Total no. of turns	32s		394		11	
Average no. of logs per turn	4.8		3.2		147.8	
Travel distances (one-way)						
Maximum (m)	140		255		600	
Average (m)	70		120		190	
Minimum (m)	10		10		30	
Summary of skidding or forwarding cycle element times	min	%	min	%	min	%
Skidding or forwarding						
Travel empty	0.81	19.1	1.43	26.2	7.77	12.3
Position-and-load	1.09	25.8	1.03	18.8	35.05	55.7
Travel loaded	1.33	31.4	1.85	33.7	9.31	14.8
Total skidding or forwarding	3.23	76.3	4.31	78.7	52.13	82.8
Decking						
Pull-in, delimb-and-pile	0.94	22.1	0.99	18.0	8.84	14.0
Clean landing			0.01	0.2		
Delays less than 15 min						
Mechanical	0.03	0.8				
Operational	0.01	0.1	0.11	2.0		
Personal	0.03	0.7	0.06	1.1	2.04	3.2
Time per cycle	4.24	100.0	5.48	100.0	63.01	100.0
Logs per PMH	69		35		141	
Turns or loads per PMH	14		11		1	
Average travel rate (min/100 m)						
Empty	1.16		1.19		4.09	
Loaded	1.90		1.54		4.90	
Total sampling time (h)	22.9		36.0		11.2	

[a] Production is based on tree-length stems skidded to roadside decks for delimbing.
[b] Production is based on stems being delimbed and cut to length at the felling site, and then forwarded to roadside decks.

The stroke delimber produced 30.6 m^3 per operating hour, worked an average of 9.8 hours per day, and required 7.6 production shifts to delimb all the decked stems (Table 16). The delimber handled 105 logs per PMH, and required .57 minutes to delimb and sever the top of aspen and conifer stems (Table 19). The delimbing and topping phase represented 90% of the work cycle, discharging debris represented 1%, moving to new landings 2%, and delays 7%. Operational delays were mainly related to waiting for logs with butt defects to be long-butted by abuckerman or the delimber operator.

The following were also required to complete harvesting on the control block:

- The contract supervisor spent two mandays laying out the block, discussing the harvesting prescription with the contractor, and preparing for the arrival of the harvesting equipment.
- A bulldozer spent 12 operating hours clearing landings and building the access road.
- The contract supervisor spent three mandays supervising harvesting operations on the block.

The cost to log the Blue Ridge control block was $14.82 per m^3 (Table 20). Felling represented 39% of the total cost, delimbing 26%, skidding 24%, preharvesting layout and on-site supervision 7%, and landing construction 5%.

Treatment 1. The use of designated skid trails, careful harvesting practices, and special techniques that reduced damage to understory, and having an interested crew, and an on-site supervisor along with the contractor, resulted in **61%** of the original understory stems being left undamaged following harvesting (Table 15). Of the understory that was damaged, 2190 was

*Table 19. Blue Ridge Work Sampling - **Delimbing**: Summary*

	Control		Treatment 1	
	No.	%	No.	%
No. of aspen logs delimbed	794	79	1036	47
No. of aspen decked only	91	9	506	23
No. of spruce processed	126	12	664	30
Total no. of logs delimbed	1 011	100	2 206	100
Summary of delimbing cycle element times	min	%	min	%
Delimbing				
Pick-up log	0.19	32.1	0.18	32.6
Process log	0.12	21.2	0.11	19.9
Top log	0.06	11.1	0.04	7.0
Put-down log	0.15	25.8	0.15	28.6
Total delimbing	0.52	90.2	0.48	88.1
Discarding junk	0.01	1.3	0.01	1.4
Moving	0.01	2.1	0.01	2.3
Delays less than 15 min				
Mechanical	0.00	0.5	0.00	0.0
Operational	0.03	5.4	0.04	7.9
Personal	0.00	0.5	0.00	0.3
Time per tree	0.57	100.0	0.54	100.0
Logs per PMH	105		111	
Total sampling time (h)	9.7		19.8	

Table 20. Costs for Blue Ridge Studies: Summary

Item	Control[a]	Treatment 1[a]	Treatment 2[b]
Volume of aspen (m^3)	1542	2354	1659
Volume of conifer (m’)	293	1375	458
Total volume (m^3)	1 835	3729	2 117

	costs ($)	No. of md[c] or OH[d]	$/m³	‘%	No. of md[c] or OH[d]	$/m³	%	No. of md[c] or OH*	$/m’	%
Preharvest										
Planning	**$400/md[c]**	2	0.44	3	10	1.07	4	2	0.38	2
Road construction & maintenance										
Bulldozer	**$107.81/OH[d]**	12	0.71	5	32	0.93	4			
Harvest operations										
Mechanical felling	$124.90/OH	83	5.65	39	225.4	7.55	30		.	-
Manual felling	**$27.00/OH**				62.0	0.45	2			
Harvester	$99.131OH					.	-	2826	13.23	58
skidding	$80.48/oH	81	3.55	24	331.3	7.15	29		.	.
Forwarder	$74.491OH		-	-		-	-	250.4	8.81	39
Re-piling	**$121.25/OH**				40	1.30	5		-	-
Mechanical delimbing	**$95.18/OH**	73.6	3.82	26	147.8	3.77	15		-	-
-Supervision	**$400/md**	3.0	065	4	26	2.79	11	2	0.38	2
Total[e]			14.82	**100 [e]**		25.01	100		22.80	100’

[a] Productions ia hazed on tree-length sterns skidded to roadside decks for **delimbing.**
b **Production** is **based on stems being delimbed and cut to length** at the **felling** site, and then forwarded **to roadside decks.**
[c] Mandays.
[d] Operating hours.
[e] **Discrepancies** in totals are due to rounding.

destroyed, 14% suffered injuries from felling or skidding operations, and 4% was harvested. Felling operations injured 8% of the residuals that remained, while skidding injured 6% and destroyed 21%.

Understory protection was rated at a high level because of the interest shown by the crew, and the use of special practices which had already proven successful on other sites. As an incentive for encouraging the crew to take the time needed to preserve residuals, the contractor was paid on an hourly basis for the rental of his equipment. Special practices incorporated into the harvesting included: using pre-located skid trails, rough delimbing and topping bunched stems prior to their skidding, utilizing as many of the trail-side aspen stumps (or poplar stems) as possible for rub posts, and cutting stumps above the height of surrounding residuals when the cutting of a normal stump close to the ground would result in injury or destruction of the adjacent understory.

Rub posts were found to be very effective in minimizing damage to understory stems adjacent to the skid trails (Figure 12). Although the number of rub posts left on the Hinton Treatment 1 block was not quantified, there appeared to be significantly more rub posts on Blue Ridge Treatment 1. A survey conducted along several portions of Treatment 1 skid trails (Table 21) determined that 10 rub posts were left per 100 m of trail (or, five rub posts on each side of the

Figure 12. Blue Ridge Treatment 1: Understory stems remaining after harvesting.

Table 21. Effectiveness of Rub Posts on Blue Ridge Treatment 2

Length of skid trail measured (m)	817
Number of rub posts	78
Number of rub posts per 100 m of skid trail	10
% of rub posts that protected understory	60
% of rub posts that had no understory to protect	40
Total of all rub posts	100
% of rub posts that were not damaged	38
% of rub posts that were slightly damaged	54
% of rub posts that were severely damaged	8
Total of all rub posts	100

trail per 100 m). Sixty percent of the rub posts were found to have protected trail-side residuals, and 62% of the rub posts were damaged by dragging logs. The significant number of undamaged rub posts indicates the crew probably left more posts than were really required and that unnecessary losses in wood fibre probably resulted. However, the presence of the potential rub posts clearly defined the location of skid trails. They made it easy for the skidder operators to follow the trails and minimized the potential for ground disturbance in areas where understory was not present. The minimization of disturbance to areas not occupied by immature stems was expected to reduce aspen competition when in-fill conifer planting occurred.

The feller-buncher, two grapple skidders, and stroke delimber produced 3729 m^3 during the Treatment 1 study (Table 16). One hand feller was employed to roughly delimb and top bunched stems prior to being skidded. The Caterpillar 235C log-loader was used to restock the log decks to reduce the size of landings.

To ensure there were sufficient bunches to keep the two skidders busy during the day, the contractor tried to double-shift his buncher by operating an evening shift. However, during night felling the operator's visibility was reduced and understory damage increased. As a result, the feller-buncher was not used to fell areas between trails during the night shift. The buncher could, however, fell skid trails during the night shift because all stems, whether merchantable or immature, were felled.

The feller-buncher produced 21.3 m^3 per operating hour, worked 9.9 hours per shift and required 22.9 production shifts to fell all the timber (Table 16). Some of the same hydraulic problems that occurred during the harvesting of the control block continued to occur while harvesting Treatment 1. The feller-buncher felled 82 trees per PMH on Treatment 1, and required .72 minutes to fell a tree (Table 17). This was a 31% reduction in production when compared to mechanical felling on the control block. Although the time required to move-to-cut, position-cut-bunch, and move-to-bunch was greater on Treatment 1 than on the control block, the felling cycle increased mainly because the feller-buncher spent more traveling time from one area in the block to another. This occurred because the trails filled up with bunches faster than the skidders could remove them, and a new work space was required to bunch the stems.

The single feller-buncher had difficulty keeping ahead of the two grapple skidders while working only a single shift per day. The merchantable stems on Treatment 1 were densely spaced and the buncher had to make three passes to completely fell an area. Because the buncher was unstable when carrying a severed stem, trees were bunched near the point of felling, resulting in a smaller than optimal bunch size.

The feller-buncher operator working on the Treatment 1 block found the work tedious. The operator became frustrated with the amount of time he spent moving his buncher, either to the next tree or to new felling areas within the block. Some of this frustration may explain the significant drop in felling productivity from the control to Treatment 1.

The two skidders each averaged 13 m^3 per operating hour, worked 9.9 hours per shift and required 33.4 production shifts to skid all the felled stems to the landings (Table 16). The skidders averaged 11 turns and 35 logs per PMH, and each turn averaged 5.48 minutes (Table 18). The number of logs skidded per PMH was half that recorded on the control block because the average load for Treatment 1 (3.2 logs per turn) was 1.6 logs fewer than for the control, and the time spent skidding increased. Skidding time increased because the average skid distance on Treatment 1 (120 m) was 70% further than skidding distances on the control block. However, while skid distance did increase, the travel speed of the skidders was nearly the same when traveling empty, and was 19% faster during the travel-loaded portion (Table 18).

Skidding production on the Treatment 1 block may have been influenced by the method of payment and the monotony associated with skidding logs along the same general route for long periods of time. The operators and contractor were paid on an hourly basis, to ensure the effort was made to protect understory stems. As a result, skidder production was less than maximum because the skidders dragged a number of one- or two-log turns from long distances.

The stroke delimber averaged 30.8 m^3 per operating hour, worked 9.5 hours per shift, and required 15.4 production shifts to process all the logs decked (Table 16). The delimber produced an average of 111 logs per PMH on Treatment 1 and required .54 minutes to process each log (Table 19). Delimber production was similar to that recorded on the control block even though some of the stems on Treatment 1 had been topped and delimbed prior to skidding. This occurred because the delimber had to either remove branches or stubs that were left on the stems, or top the stems at the minimum diameter set by the mill.

The presence of the contract supervisor and the contractor during the harvesting operation had several benefits. It helped the operators develop work patterns that minimized damage to the understory. Skid trails were laid out so that the equipment could operate productively while as much understory as possible was protected. The contract supervisor ensured that the flagging marking the trails and boundaries was visible to the buncher operator and he organized and scheduled the crews so that conflicting activities were avoided. The contract supervisor also arranged for mechanical repairs when required.

The following were also required to complete harvesting on Treatment 1:

- The contract supervisor spent 10 mandays laying out the block, laying out skid trails, discussing the harvesting prescription with the contractor, and organizing auxiliary equipment to work at the site.
- A bulldozer spent 32 operating hours constructing the truck road to access the landings.
- One hand feller spent a total of 62 operating hours rough delimbing and topping bunched aspen and conifer stems.
- A hydraulic loader worked 40 operating hours restacking decks to allow more logs to be decked without expanding the landing areas.
- A contract supervisor spent 26 mandays supervising harvesting operations at the block.

The cost to harvest the Blue Ridge Treatment 1 block was $25.01 per m^3 (Table 20). Felling costs on Treatment 1 represented 30% of the total harvesting costs, skidding 29%, mechanical delimbing 15%, preharvest organization and on-site supervision 15%, landing construction 4%, restacking decks 5%, and manual delimbing (manual felling) 290. Harvesting costs on Treatment 1 were 69% more than the control block. The increased costs were associated with the decreased production of the feller-buncher and skidders, more work required of the bulldozer, and the costs associated with auxiliary items not required on the control block (on-site supervision, restacking decks, rough delimbing and topping in the bush, and preharvesting layout).

Treatment 2. The Blue Ridge Treatment 2 block was harvested with an intermediate level of understory protection, whereas the Hinton Treatment 2 crew took considerable care in protecting as much of the understory as possible. In particular, the crew at Blue Ridge did not flag the trails and therefore were not as active in protecting understory stems. However, the operators did walk the block.

Results of the post-harvesting surveys (Table 15) indicate that 21% of the understory was left undamaged on the Blue Ridge Treatment 2 block, 51% was injured, 1890 was destroyed, 9% was harvested, and 2% blew down after harvesting (Figure 13). The felling and processing phase injured 30% of the residuals and destroyed 3910, while the loading and forwarding phase injured 21% and destroyed 15%.

The understory damage recorded at the Blue Ridge Treatment 2 site, where the original understory densities were similar, was 40% greater than that recorded at Treatment 1 (Table 15),

Figure 13. Blue Ridge Treatment 2: Understory stems remaining after harvesting.

and 10% greater than the damage recorded at Hinton Treatment 2 where the understory was much denser. (Table 9). The difference in understory protection of the Treatment 1 and 2 sites at Blue Ridge occurred because the harvesting equipment and the equipment work patterns were different. The difference in understory protection at Hinton and Blue Ridge (where the same type of equipment was used on both Treatment 2 sites) was a result of varying work patterns and level of operator experience.

The difference in understory protection at the Blue Ridge Treatment 1 and 2 sites was attributed to the different work patterns employed by the conventional roadside harvesting equipment and the Swedish harvesting system (described in the results for the Hinton Treatment 2 study). Another factor that influenced the amount of understory that was destroyed was the harvesting of minimum-diameter immature stems.

The single-grip harvester operated somewhat differently from the double-grip. The double-grip used the felling head to place the severed stem into the processor mounted on the back of the harvester carrier. Limbs cut from the stem fell beneath the processor onto the trail. The single-grip harvester utilized a harvester head that could fell, delimb, and buck the stems into log lengths. Because the harvester head was mounted at the boom's end, the limbs severed from the stems were left beside the trails. Both types of harvesters pulled the stem through the processing units, and each time the limbs on the stem brushed against understory residuals. As a result, the harvesters tended to injure rather than destroy (kill) a larger number of understory stems, and a number of stems of questionable future value were left.

The single-grip and double-grip harvesters worked in separate areas of the block, with the double-grip processing the larger aspen and the single-grip processing the smaller trees. The harvesters did not follow flagged trails, but cut trails perpendicular to the main road as required. Trail spacing depended on the felling head reach, and usually ranged between 10 and 15 m. The forwarders followed the same trails as the harvesters and operated about one-half shift behind.

The Treatment 2 area had several very wet areas that would have prevented the use of conventional harvesting equipment. At these places, both harvesters tried to place most of the limbs and tops from the processed stems on the trail. The limbs and tops provided a mat that supported the harvesters and forwarders over the wet, soft terrain. This limited soil compaction, rutting, and damage to the root structures of adjacent understory stems. However, operating on designated skid trails and on ground moist from heavy rain did cause some rutting.

The two harvesters and two forwarders produced 2117 m^3 of aspen and conifer logs cut to 4.9-9.8-metre (16-32 foot) lengths (Figure 14) from the Treatment 2 block. Table 16 summarizes the harvester and forwarder production. .

The two harvesters each produced an average 9.3 m^3 per operating hour, and worked an average of 11.8 hours per shift for 24 production shifts (Table 16). The harvesters each felled 59 trees per PMH and required 1.03 minutes to fell and process a tree into logs (Table 17). The harvesters spent 86% of their work cycle felling and processing stems, 290 of the cycle moving to new work areas within the block, and 12% of the cycle not working because of delays. Half of the mechanical delay time that occurred during both the shift-level and work sampling studies was associated with servicing, cleaning the units, and warming the engine and hydraulic systems prior to operation. The remainder was associated with repairing air-conditioning units, replacing sawbars and sawchain on the felling and processing heads, and repairing or replacing hydraulic hoses and cylinders. The operational delays were all due to lunch, dinner, and operator breaks.

Figure 14. Blue Ridge Treatment 2: Rutting caused by forwarder operating on a designated skid trail on moist soft ground.

Harvester productivity (m^3 per operating hour) was 56% less than that of the feller-buncher operating on Treatment 1 (Table 16) because it took the harvester nearly four times longer to handle each tree than the feller-buncher required (Table 17). The difference in time required to handle each tree occurred because the feller-buncher and harvester had two different work cycles and produced two different forms of logs. The feller-buncher felled and bunched only full-length stems while the harvesters felled, delimbed, and cut the stem into log lengths. In addition, the aspen piece size at Treatment 2 was nearly half that for Treatment 1 (Table 14). Harvester productivity (m^3 per operating hour) at Blue Ridge Treatment 2 was 13% less productive than harvester production at Hinton Treatment 2 (Tables 10 and 16) because the larger piece size (Tables 8 and 14) at Hinton compensated for an increased processing time. Processing time per tree at Blue Ridge was less than half the processing time at Hinton because the Blue Ridge Treatment 2 trees were smaller and, therefore, fewer cuts were needed to process the stem into log lengths. In addition, processing time was also faster at Blue Ridge because the moderate understory density did not interfere with the felling and processing operation.

The two Blue Ridge forwarders each produced an average 10.1 m^3 per OMH, worked an average of 10.9 hours per shift, and required 23 production shifts to bring the 2 117 m^3 of aspen and conifer to the roadside deck (Table 16). The forwarders averaged one load per PMH and carried 141 logs to roadside on each trip, taking 63.01 minutes to complete each load (Table 18). The average travel distance from the deck to the loading point was 190 m, and ranged between 30 and 600 m.

Forwarder productivity at Blue Ridge was lower than at Hinton Treatment 2 because loading time was longer, the time to travel with a load to the decking area was longer, and the operators were less experienced. Loading time at Blue Ridge Treatment 2 was longer than at Hinton (Tables 12 and 18), the trees were smaller, creating smaller piles of processed logs and requiring more moving time by the forwarder. Travel time to the decking area increased because the ground at Blue Ridge was rougher and softer than at Hinton.

The following were also required to complete harvesting on Treatment 2:

- The logging supervisor spent two mandays laying out the block, explaining the harvesting prescription to the crew, and preparing for equipment arrival.
- The logging supervisor spent two mandays supervising harvesting operations on the block.

The cost to harvest the Blue Ridge Treatment 2 block was \$22.80 per m^3 (Table 20). Felling-processing costs on Treatment 2 represented 58% of the total harvesting costs, forwarding 39%, and preharvest organization and on-site supervision 470. Although the harvesting costs on Treatment 2 were \$8 per m^3 higher than the costs to harvest the control block, the costs were similar to the Hinton Treatment 2 block that was harvested using similar equipment. The differences in harvesting costs for Blue Ridge blocks resulted because the Scandinavian equipment had relatively low productivity relative to its capital costs and different rates of production.

Discussion

The results of using feller-bunchers and grapple skidders to protect understory stems on Treatment 1 resulted in an understory stand that had a different appearance than the Treatment 2 stand harvested by harvesters and forwarders. Similar observations were made at Hinton study sites. The feller-bunchers and grapple skidders left islands of undamaged understory between well-defined skid trails. Between trails, the harvesters and forwarders left a significant number of damaged understory stems that were much less visible than those used by conventional equipment. This was the result of the two different work patterns. These work patterns have been described previously, in the Hinton Case Study.

The 2% of understory stems that were recorded as blowdown on Treatment 2 was greater than any recorded in the previous studies. Future monitoring of Blue Ridge Treatment 2 and the other treatment blocks and re-surveying the sample plots will better indicate the wind-firmness of the residual conifer stand.

The moderately stocked preharvest understory at Treatment 1 and 2 made it easier for equipment operators to protect residuals during harvesting. The open spaces between understory stems made skid trail construction less damaging to residuals and allowed the buncher or harvester operator to place the felling head around a merchantable stem without damaging adjacent residuals. However, the post-harvest survey indicated there were probably insufficient understory stems to achieve a stocking level required to establish a conifer land base on Treatment 1 even though the high level of protection managed to save undamaged, 61% of the residual stems.

DISCUSS1ON

Research results at the three case-study sites indicate that once spruce protection prescriptions are agreed upon there are several key aspects that will minimize damage to understory stems during harvesting. These factors are equipment selection, on-site supervision, operator co-operation, the use of rub posts, the time of harvesting, and cooperation of provincial authorities.

Equipment Selection

While the special practices used during harvesting were the prime reason for a reduction in understory damage, study results indicated that machine selection also played a key role.

The results of post-harvesting studies indicated that the skidding phase was the most injurious to understory largely because of the area required for skid trails. However, felling practices ultimately determined how much understory was left undamaged. Felling not only damaged understory directly through the impact of the dropping trees, but also through the influence of alignment and position of felled stems when subsequent processing forwarding or skidding occurred. As a result, how the equipment felled a tree and the design of the felling equipment played significant roles in the amount of understory that was left undamaged by the harvesting operations.

During the harvesting trials, it was apparent that the way equipment felled a tree directly influenced the amount of understory protected (or damaged). For example, the understory residuals growing between skid trails were not significantly damaged when a feller-buncher felled the mature stems because the feller-buncher could control precisely the fell of the stem. As a result, the stems were bunched where there was no understory, or where understory damage would be concentrated into a small area. On the other hand, most of the mature stem felled with the harvesters fell amongst understory residuals. These residuals were injured when the mature stem fell, or as the stem was dragged through the harvester head for delimbing and cutting to length.

Feller-buncher design influenced understory protection in several ways. Firstly, excavator-type feller-bunchers had larger swing radii than either the harvesters or the Timberjack 2500 series feller-buncher due to their counterweight location. This wider swing increased skid trail width and caused more understory damage beside the trails. Secondly, the cab location also influenced the amount of understory damaged. The cab on the feller-buncher was much higher off the ground than that of the harvester or front-end loader feller-buncher, which permitted the operator to see over dense patches of understory. The harvester and forwarder cabs were the largest of all the equipment and provided the best all-around visibility. The large cab also provided an opportunity for two operators, or an operator and the supervisor to work together to determine the best strategy that would minimize understory damage.

The width of harvesting equipment and the method used to bring the stems or logs to roadside appeared to influence the degree of skid trail damage. It was observed during the trials, that the most well-defined trails were those created with the feller-buncher for a skidder. This was because the long stems bunched on the trails required relatively straight lengths or long, smooth curves for efficient skidding, and the dragging of logs along the trails scraped away the top surface of the soil. On the other hand, the narrowest and least-defined skid trails were created by the combination of harvester and forwarder. These trails did not have to be straight because the mature stems were processed perpendicular to the trail and left as log lengths beside the trail for the forwarder to recover, and the trail surface was not scraped because the logs were carried by the forwarder.

The size and design of the felling head attachment selected for the feller-buncher also contributed to the protection of understory stems. The narrower the head, the less chance for immature stems to be damaged when the mature stem was cut. The harvester operator had a better view of the harvester head than the feller-buncher operator had of the feller-buncher head. However, because the harvester head was so light, it frequently tangled around dense understory stems and could not be placed around the mature stem. The harvester would then have to fell and process a number of understory stems to provide a clear path to the mature stem. The operator's view of both Timberjack 2500 and 618 series feller-buncher heads was often obscured by the boom and stick assembly, or the back of the felling head. As a result, understory spruce were unintentionally damaged.

The type of device used to sever the stem also contributed to understory damage. The shear and chain saw felling heads would cut an understory stem only if it was caught in the head when cutting action was initiated. However, the continuously rotating high-speed Timberjack 618 disc saw would inadvertently sever understory stems if the operator was not careful where the head was placed. For this reason, an intermittent type disc saw head would be less damaging to understory stems in a mixedwood harvesting operation.

The selection of equipment should also consider the work cycle required when understory stems are to be protected during harvesting. Results of productivity studies indicate that protecting conifer understory during harvesting operations changes the work cycle of equipment, which may in turn increase stresses on components that would not normally be stressed as severely. For example, feller-bunchers working in stands where advanced regeneration is to be protected would be required to move more often around the felling site and travel longer distances with one or more severed stems in the felling head. These demands would increase stresses on travel motors, final drives, undercarriage, boom and stick assemblies, and the felling head.

When using the designated skid-trail pattern over wet ground, consideration must be given to the selection of the most appropriate log-extraction equipment. Because traffic along the designated trails is concentrated and repeated for a number of cycles, there is the potential for ruts to develop in local areas of soft, wet soil. The forwarder appeared better suited than the skidder for operating over soft, wet ground because the combination of wheels and tracks on the forwarder were able to distribute the load. Forwarder flotation was also assisted when the harvester spread limbs and tops over the trail. The skidder, on the other hand, was limited to the flotation provided by the four skidder tires.

The double-grip harvester was suited to working in stands of larger diameter stems (between 25-46-cm diameter) and the single-grip harvester was best suited for smaller diameters (10-30 cm). This was because the small diameter feed rollers on the single-grip harvester were not large enough, nor powerful enough to propel a large diameter stem through the delimbing knives. The large rubber-tired feed rollers on the processor of the double grip harvester could easily handle the larger stems.

Apart from handling different sizes of stems, there was no clear advantage to using either a single- or double-grip harvester: neither unit had directional felling capability, both units caused residuals to be damaged when the felled stem was pulled toward the carrier and when the stem was processed, and both could process stems so that the slash was deposited on the access trail. However, the single-grip harvester was also able to process stems away from the trail if debris was not required to be placed on the trail. This would disperse the limbs and tops over the block. The double-grip harvester, however, always placed limbs and tops on the trail.

Supervision

In all sites where an on-site supervisor was present, production was improved. The supervisor was available to: sort out scheduling difficulties between equipment; resolve problems arising from skid trail layout, provide encouragement and compliments to the crew when necessary, and assist with mechanical repairs.

Also, the on-site supervisors learned more about skid-trail layout and landing selection as trail-building progressed. Simple skid-trail layouts worked the best, and trails that were well flagged increased the efficiency of the feller-buncher. Supervisors realized that understory damage resulted when bunches, placed in a herringbone formation off the skid trail, were dragged into the trail. The least damage occurred when the bunches were accumulated along the skid trail.

The presence of an on-site supervisor improved the work habits of operators who were not interested in the study. When the supervisor was present, skidder operators did not cut across trails as they travelled to and from the landing or when they recovered logs left from previous skidding. By watching the felling and skidding equipment operate, the supervisor could assist all operators improve their performance by ensuring the skid trails were well located and providing advice on work patterns to all operators.

Operators

The understory would not have been protected as well without the cooperation and support of the equipment operators. To comply with the objective, they were faced with devising modified operating techniques for their equipment. They had to maintain enthusiasm and responsibility for the project even when production was reduced.

Good communication between the supervisors and crew was the key to successful understory protection. Operators wanted to know the objectives of the study, and how the techniques proposed would protect residuals. However, it was sometimes difficult to convince an operator, interested only in production, that there was merit in protecting understory, especially when there was no additional monetary benefits for the extra effort or potential reduction in production. Nonetheless, the majority of operators that participated in the study understood the rationale and viewed their efforts with pride. As a result, operator dedication to the project was high and they developed their own techniques. Their performance would probably continue to improve with experience.

At the beginning of each study, all feller-buncher operators found it difficult to decide which understory stems should be saved. As a result, the feller-buncher operators were instructed to remove all the understory stems that would likely be damaged by skidding and to avoid protecting single stems if there was a good chance of them being damaged during skidding. The pre-located and flagged skid trails assisted the feller-buncher operators because they knew the trails were properly located and that all stems located on the trail had to be felled. In addition, the buncher operators observed the skidding phase and adjusted the trail location to avoid sharp comers.

When the areas between trails were felled, the buncher operators used their own judgement in locating access trails. Buncher operators minimized understory damage when working in dense understory clumps by entering the clump only if there were merchantable stems of sufficient value to offset the damage. In most cases, the buncher could take advantage of natural openings within the stand to access merchantable stems.

The skidder operators sometimes modified the trails to increase their production or to reduce trail-side residual damage. When skid trail curves or junctions were tight, the dragging turns would swing into trail-side residuals located on the outside of the turn, and the middle portion of the dragging logs would pivot on the residuals located on the inside of the curve. Skidder operators were encouraged to make any modifications to the trails as early in their skidding cycle as possible, so that all the following turns would minimize trailside damage and also be more productive. Skidder operators were discouraged from pushing aside understory at the end of skidding or during clean-up operations, as this would have little benefit to productivity. The use of rub posts confined dragging stems to the trail and minimized widening.

During the case studies, operators were paid by two different methods and both appeared to influence the interest of the crew in protecting understory. At Drayton Valley, where the crew received no additional financial incentive for their effort, the crew was not willing to incorporate any special techniques that might interfere with their production. At Hinton and Blue Ridge, where the crew were paid on an hourly rate, they did not mind changing their work patterns. However, the Hinton and Blue Ridge crews were also very conscious of production. All crews took pride in what they had accomplished. These observations suggest an effective method of paying crew should incorporate both a base rate for harvesting and an incentive for achieving a specific goal; in this case, protecting the understory.

Rub-Posts

The practice of leaving rub-posts beside the skid trails and high stumping merchantable stems when nearby understory residuals could be damaged by the felling head was found effective in reducing overall understory damage. However, leaving high stumps also has a cost in terms of lost fibre yield. This fibre loss could be reduced by not felling the trailside trees until all the remaining stems have been skidded, and then felling and skidding the merchantable stems along the skid trails, beginning at the back of the block and working towards the landing.

Two operating strategies are suggested if high stumping is to be used for understory protection.

The first would leave the high stumps as they remain if the butts of aspen stems were found to be heavily stained and more than 50% rotten. A second strategy would be to have the rub-posts left with a stump height that would allow for reasonably efficient forwarding to roadside and transportation to the mill.

Time of Harvesting

When it was not feasible to access the block during the summer due to soft ground, harvesting took place during the early spring when the ground was frozen, thus ensuring all the merchantable fibre was harvested and that a significant portion of the advanced regeneration was protected. This also reduced rutting and soil compaction. Harvesting operations during sub-freezing temperatures did not necessarily increase understory damage. Observations at the Blue Ridge Treatment 1 block indicated that as long as the feller-buncher could maintain control of the stem during felling, damage to understory from felling did not increase during the sub-freezing temperatures that occurred during portions of the trial.

Cooperation of Provincial **Authorities**

Operating decisions that would influence the type and amount of slash, reduce the amount of fibre recovered from a block (such as from leaving rub-posts or sub-merchantable stem), or result in soil disturbance are critical to the adoption of methods to protect understory. They can be adopted only when the provincial authorities cooperate with the harvesting contractors and forest licence holders, to waive or modify utilization ground rules as required.

CONCLUSIONS

This report presents costs and productivity results, as well as results about harvesting-related darnage incurred by the understory in a mixedwood harvesting trial. The trial compared conventional and Scandinavian harvesting equipment, levels of operational supervision, and special operational techniques. The study results were drawn from trials carried out in the northern boreal forest region of Central Alberta, between October 1988 and June 1990. FERIC conducted the harvesting cost and productivity study for the Northern Forestry Centre of Forestry Canada, who conducted the harvesting-related damage component.

Study findings indicate that 40%-60% of the understory can be protected with varying increases in harvesting cost. Costs at three treatment blocks varied because some protective harvesting practices increase costs, while others actually reduce them. Costs increased at three treatment blocks because at one block feller-buncher and skidder productivity was significantly reduced by the special harvesting practices, and at two blocks, a more expensive, less productive harvesting system was employed.

Results of post-harvesting surveys indicate conventional feller-bunchers and grapple skidders protected more advanced regeneration than Scandinavian equipment (Table 22 and Figure 15). The amount of understory injured and destroyed when conventional equipment was used decreased as more intensive practices to protect the understory were incorporated into the harvesting plans and operations: from 82 to 91% of the understory being injured when no special practices were utilized, to between 38 to 55% with intermediate measures, and between 35 to 47% with high protective measures. The Scandinavian equipment left 69% of the understory injured or destroyed when intermediate and a high level of understory protection were incorporated into the harvesting operations. When conventional equipment was utilized, the

Table 22. Summary of Understory Stems Damaged During Harvesting

Study site	Understory Stems Damaged				
	Injured (%)	Destroyed (%)	Total Injured and Destroyed (%)	Harvested (%)	Total Damaged (%)
BLOCKS WITH LOW UNDERSTORY PROTECTION EFFORT:					
Mechanically felled and grapple skidded					
Hinton: Control	31	52	82	2	84
Blue Ridge: Control	7	84	91	7	98
BLOCKS WITH INTERMEDIATE UNDERSTORY PROTECTION EFFORT:					
Mechanically felled and grapple skidded					
Drayton Valley: Control	31	25	56	5	61
Drayton Valley: Treatment 1	30	25	55	2	57
Drayton Valley: Treatment 2	25	13	38	1	39
Felled and processed at stump, forwarded to roadside					
Blue Ridge: Treatment 2	51	18	69	9	78
BLOCKS WITH HIGH UNDERSTORY PROTECTION EFFORT:					
Mechanically felled and grapple skidded					
Hinton: Treatment 1	29	18	47	1	48
Blue Ridge: Treatment 2	14	21	35	4	39
Felled and processed at stump, forwarded to roadside					
Hinton: Treatment 2	52	17	69	1	70

amount of understory destroyed decreased significantly when understory protection practices were incorporated into the harvesting operations: between 52 to 84% with no understory protection, between 13 to 25'% with intermediate protection and between 18 to 21% with a high degree of protection. Scandinavian equipment injured significantly more understory (51 to 52%) and destroyed fewer understory stems (17 to 18%) when compared to conventional equipment that injured between 14 to 30% and destroyed 13 to 25% of the residuals.

The differences in understory protection of the conventional and Scandinavian harvesting equipment were directly related to the method of felling and skidding. Conventional harvesting equipment left well-defined skid trails with islands of relatively undamaged understory between the trails. Scandinavian equipment left skid trails that were less visible than the conventional equipment; however, significantly more of the understory between trails was injured than with conventional equipment.

Study results (Table 23 and Figure 15) indicated that the cost for harvesting areas using conventional equipment increased as the level of understory protection increased. Conventional harvesting costs ranged between \$14.70 to \$14.90 per m^3 when the understory was afforded no protection, between \$13.90 to \$17.40 per m^3 when an intermediate level of understory protection was utilized, and between \$18.40 to \$25.00 per m^3 with a high degree of understory protection. The cost for harvesting areas with Scandinavian equipment was similar for the sites that were

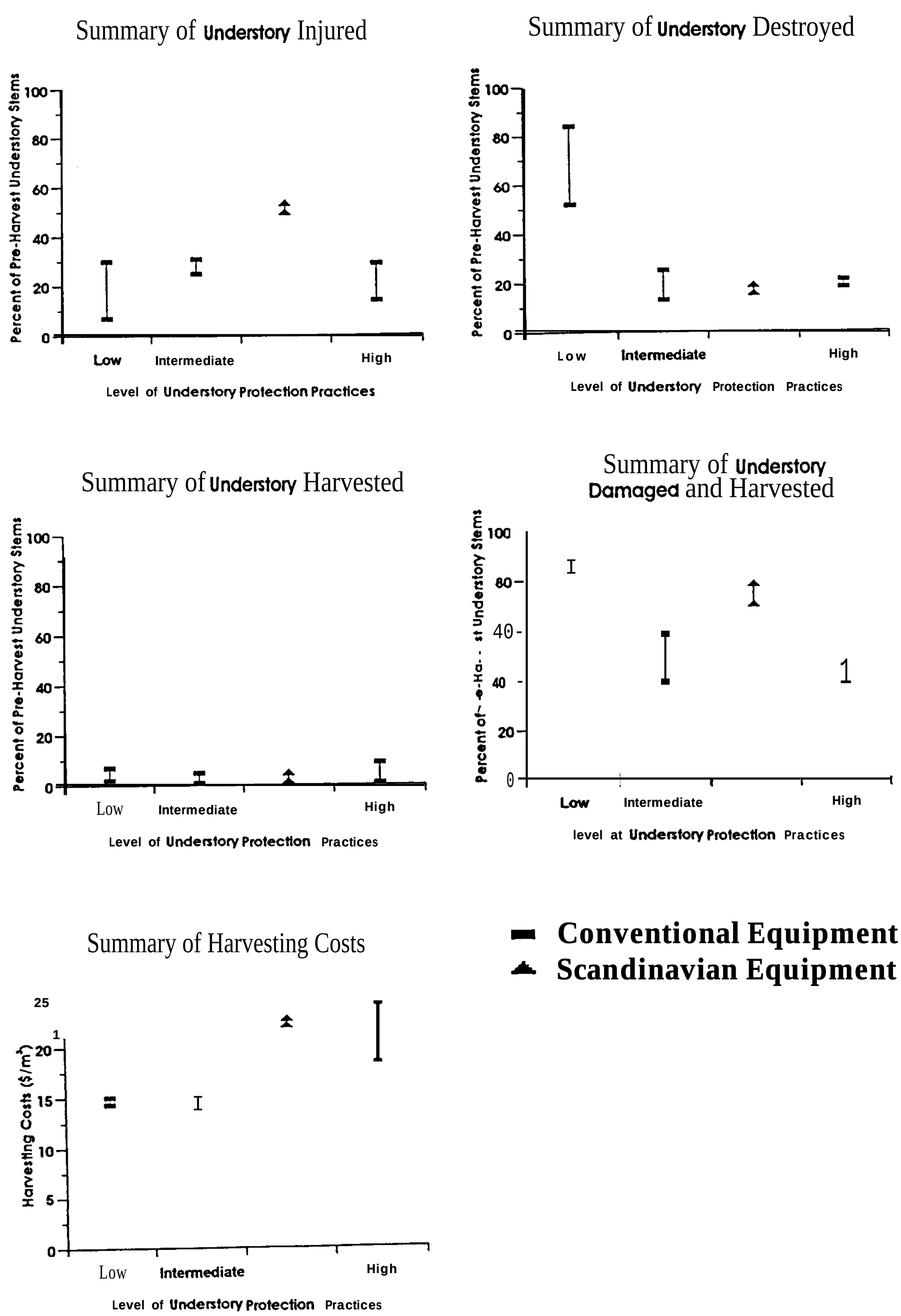

Figure 15. Understory damage and harvesting cost summary.

Table 23. Harvesting Costs: Summary

Study site	Cost centres: Pre-harvest organization ($)	Cost centres: Falling or fell/process ($)	Cost centres: Skidding or forwarding ($)	Cost centres: Bush delimbing and topping ($)	Cost centres: Delimbing ($)	Cost centres: On-site supervision ($)	Sub total ($)	Additional costs: Bulldozer ($)	Additional costs: Other ($)	Total cost ($)
BLOCKS WITH LOW UNDERSTORY PROTECTION EFFORT:										
Mechanically felled and grapple skidded										
Hinton: Control	0.30	4.90	4.60		2.40	0.50	12.70		2.00”	14.70
Blue Ridge: Control	0.40	5.70	3.60		3.80	0.70	14.20	0.70	-	14.90
BLOCKS WITH INTERMEDIATE UNDERSTORY PROTECTION EFFORT:										
Mechanically felled and grapple skidded										
Drayton Valley: Control	0.30	2.50	8.90		2.80	0.10	14.60	2.00	0.3&	16.90
Drayton Valley: Treatment 1	0.30	2.00	7.30		3.10	0.20	12.90	0.60	0.40[c]	13.90
Drayton Valley: Treatment 2	0.30	3.00	8.80	1.40	3.00	0.30	16.80	0.60	-	17.40
Felled and processed at stump, forwarded to roadside										
Blue Ridge: Treatment 2	0.40	13.20	8.80			0.40	22.80		-	22.80
BLOCKS WITH HIGH UNDERSTORY PROTECTION EFFORT:										
Mechanically felled and grapple skidded										
Hinton: Treatment 1	2.00	5.20	3.20	1.10	2.30	2.30	16.10	0.80	1.50[d]	18.40
Blue Ridge: Treatment 1	1.10	7.50	7.10	0.50	3.80	2.80	22.80	0.90	1.30$	25.00
Felled and processed at stump, forwarded to roadside										
Hinton: Treatment 2	0.60	12.50	9.00			0.20	22.30		0.20[f]	22.50

[a] Includes manually falling ($0.60/m³) and mechanical slashing ($1.40/m³).
[b] Includes manually falling ($0.30/m³).
[c] Includes manually falling ($0.40/m³).
[d] Includes mechanical slashing ($1.50/m³).
[e] Includes restacking log decks ($1.30/m³).
[f] Includes manually falling ($0.20/m³).

harvested using intermediate and high degrees of understory protection, and ranged between \$22.50 to \$22.80 per m³. Total harvesting costs varied because tree size, log size andequipment production rates varied between studies; additional tine was required to organize the equipment prior to harvesting and to supervise the equipment during harvesting; additional work was required to manually delimband top stems prior to skidding, and additional costs (such as road and landing construction, manual felling, and mechanical slashing) were incurred on some blocks and not on others.

Felling and bunching costs on the treatment 1 blocks at Hinton and Blue Ridge were higher than the control block, and lower for the two treatment blocks at Drayton Valley. The increases were a result of reduced production caused by smaller trees and increased time spent felling each tree. Felling and bunching time increased because the bunchers spent more time traveling to new areas within the block and more time traveling to cut and bunch stems than with conventional felling.

Felling and processing costs using the Scandinavian equipment were lower on the Hinton Treatment 2 block than the Blue Ridge Treatment 2 mainly because the tree size was larger at Hinton.

When compared to their control blocks, skidding costs on both treatment blocks at Drayton Valley and Treatment 1 at Hinton were lower, and higher at Blue Ridge Treatment 1. Forwarding costs at both study sites were the same. Although skidding cycle times increased in the treatment areas where protective harvesting methods werepractised, skidding costs decreased because they were offset by more logs being skidded per cycle, and the logs being larger. Skidding cycle time on the treatment blocks increased because skidding distance increased and more time was spent traveling to pick up or bring back a turn. However, travel time did not increase in direct proportion to the increased distances because the skidders travelled faster when following the carefully aligned skid trails on the treatment blocks.

The potential to incur further equipment operating costs also exists. FERIC observed that the feller-bunchers spent more time traveling between work areas. This could lead to increased undercarriage costs. Longer skidding distances will, of course, increase tire costs.

The special practices used on the treatment blocks increased harvesting costs. Pre-harvest organization remained the same for the Drayton Valley studies, increased by \$.20 per m³ for the Scandinavian equipment, and increased by \$.70-\$1.70 per m³ for the Hinton and Blue Ridge feller-buncher and grapple-skidded treatment blocks. These costs increased in direct proportion to the additional time spent by planners or supervisors at the various treatment studies. FERIC found that on-site supervisors had as much influence expediting work and reducing costs as did careful pre-harvest planning. Rough delimbing and topping of stems prior to skidding increased costs by \$.50-\$1.40 per m³.

RECOMMENDATIONS

FERIC found that the following protective harvesting methods will limit understory damage.

Planning: Careful planning is required before an area is harvested. Sites which are too wet for summer logging should be winter logged. The boundaries of the cut area should be clearly defined. The landings should be placed in areas where there is minimal spruce understory. Skid trails should be planned and clearly marked. Such trails should be configured to avoid right-angle corners and intersections of more than two trails.

Proper equipment selection: Selecting the most appropriate equipment will assist in reducing damage to spruce understory stems. Ensuring that felling equipment cuts a trail wide enough for the skidders or forwarders will minimize the number of trail-side residuals damaged. When selecting a feller-buncher, consideration should be given to one that has a high cab (for all-around visibility), minimal counterweight overhang, good balance (for traveling with a severed stem), and, a boom and stick design that brings the felling head close to the centre of the machine. The felling-head should have a narrow profile so it can fit between stems. Skidding or forwarding equipment should have sufficient flotation for the ground conditions, remembering that designated skid trails concentrate skidding traffic.

Study results suggest the Scandinavian harvester is best suited to mixedwood stands having merchantable stem diameters less than the 46 cm (18 inches) cutting capacity of the felling head, and stands having a relatively open understory. Dense understory stands are not suited to this style of harvester because the small stems restrict the head's access to merchantable stems. Also, when the stem is felled, it must be pulled through the understory during processing. The single-grip harvester was better suited to the smaller diameter ranges, and the double-grip harvester to the larger ranges.

On-site supervision: On-site supervision can contribute to reducing understory damage and costs. An on-site supervisor ensures the crew clearly understands how the harvest plan will be implemented and what their participation will be. The on-site supervisor can also suggest operating techniques that balance the trade-offs required for understory protection and operator productivity; such as, ensuring skid trails and boundaries are clearly flagged prior to felling. The on-site supervisor should also be able to minimize delays associated with repairs and maintenance by making decisions regarding mechanical assistance and parts.

Modification to operating techniques: Modified operating techniques are required during the harvesting phase to minimize damage to understory stems. A designated skid-trail network, rather than a random pattern of skid trails, should be used. Trailside nonmerchantable trees should be used as rub posts. Stems should be limbed and topped prior to skidding. Bunches should be placed in a shingle-pattern along the skid-trails with the tops of one bunch over the butts of the next bunch. The cutting height of merchantable trees should be raised above ground level if surrounding understory stems could be damaged by the felling head, or if the lower portion of the stem has a high degree of rot. Handfelling should be minimized to reduce the number of stems that fell uncontrolled into understory stands. Understory damage can also be reduced by not felling single, standing, isolated, merchantable stems of marginal quality; stems of marginal size; or nonmerchantable stems that would damage significant numbers of residuals if felled. Ensuring skidders do not cut across trails or take short-cuts to the landing will further reduce the number of understory stems damaged during harvesting.

When merchantable stems have to be left as rub-posts, they should not be felled until all the other stems have been skidded. The rub-trees can then be felled and skidded, beginning at the back of the block and working toward the landing. An alternative would be to leave the stem high enough to provide a log length sufficient for forwarding to roadside and transporting to the mill. When extensive rot or stain is found in the lower stems, consideration should be given to leaving the rub-posts without utilization penalties being incurred.

Crew Motivation: An incentive program that emphasizes protecting understory should be considered. Such a program should complement the operator's existing base rate payment system. The base rate should reflect the actual costs of harvesting the block. Crews that do a good job protecting understory stems should be used as examples, their work and skills advertised. Crews that cannot or will not take the necessary steps to protect understory stems should not be allowed to operate in mixedwood stands. Operators should also be appraised before hand that a poor performance will disqualify them from future work.

Training: The training of supervisors and operators in the effectiveness of modifying harvesting operations for reducing damage to understory stems will reduce the time associated with learning new skills on the job, will provide guidance to supervisors so they understand what proportion of advanced regeneration can be protected during harvesting. When this information is provided to supervisors and operators, the amount of direct supervision will be reduced, and the cost of harvesting mixedwood stands where the advanced regeneration is to be protected will be reduced. The information collected during this study would provide the basis for an effective training program.

Cooperation from Other Agencies: Provincial authorities must cooperate with equipment operators, contractors and licence holders when enforcing operational ground rules for utilization and ground disturbance. The protection of understory residuals will be feasible only if provincial authorities and licensees can agree on the need to develop rub-posts from sub-merchantable stems, distribute slash over the block to improve flotation, or exceed soil disturbance standards on localized portions of a cutblock to utilize designated skid trail systems.

APPENDIX I

Summary of Understory Damage Assessed by Forestry Canada During Post-Harvesting Surveys

Understory stems with no visible damage, or superficial damage were classified only as stems with "no injury."

Understory stems that had the following characteristics were classified as stems that had been "injured.' '-The injuries were considered non-life-threatening, and some stems would probably become mature crop trees.

- Broken or lost leader*
- Dead terminal bud
- Broken branches*
- Multiple leaders
- Dead top
- Bark scrape on stem*
- Bark scrape on stump/root collar (within 30 cm of ground)*
- Bark scrape on roots*
- Leaning 1-30 degrees*
- Weevil present on stem
- Stem disease
- Foliar insect present
- Foliar disease present
- Bark beetle present

Understory stems that had the following types of damage were classified as stems that had been "destroyed." The stem was either not present or so severely damaged that it was unlikely to become a mature crop tree.

- Broken stem*
- Leaning 31+ degrees*
- Standing dead
- Missing*

*Attributed to harvesting operations.

APPENDIX II

Description of Timing Elements for Shift-Level Studies

*Production (or productive) **shift*** - Any shift where the machine was performing a function for which it was scheduled.

*Operating Machine **Hours** (OMH)* - The time during which the machine was in motion. OMH includes the time the machine spent traveling to and from the work site, or undertaking miscellaneous tasks such as reconnaissance, towing log trucks, or assisting with repairs to other machines. Because the OMH are recorded on a chart and are not identified by specific activities, the proportion of time actually identified as productive, or directly related to the main equipment activity cannot be determined.

Scheduled Machine Hours (SMH) - The time during which the machine was regularly scheduled to do productive work, e.g., eight or nine hours per shift, with one, two, or three shifts per day. Scheduling refers to machine time, not operator's time. For example, an operator's regular half hour break for lunch was not included in SMH. The scheduled in-shift time was divided into:

- Productive machine time (hours)
- Mechanical delay time (hours)
- Nonmechanical delay time (hours)

Mechanical Delay Time [Mechanical Delay Hours (MDH)] - That part of scheduled machine time required to repair or replace part(s) due to failure or malfunction. It also included daily servicing, fuelling, modifications and improvements of the machine, and waiting for parts and mechanics.

Nonmechanical Delay Time [(Nonmechanical Delay Hours (NDH)] - That part of scheduled machine time during which the machine was not doing productive work for reasons other than mechanical reasons. Nonmechanical delays were further divided into:

- Operational delays: any event associated with routine harvesting activity that prevented the equipment from actively felling, skidding, or delimbing stems.
- Personal delays: any event, caused by the operator, stopping the routine work cycle.

APPENDIX III

Description of Cycle Time Elements for Work Sample Studies

Felling (feller-bunchers and single- or double-grip harvesters):

Move-to-cut: any travel by a carrier to reach a new tree after bunching or during an accumulation of trees sequence. Starts and ends with track movement.

Position-and-cut: any cab and/or boom movement involved in positioning the felling head for the next cut, severing the tree, and moving the boom to bring a load of trees to the bunching point. Starts at the end of the move-to-cut cycle, includes any severing action and bunching movement that doesn't involve track movement, and ends when the carrier tracks begin movement to the next tree.

Move-to-bunch: any carrier movement that brings a load of trees to the bunching point. Starts after position-and-cut and ends when the trees are dropped on the ground.

Move-to-process: any carrier movement that brings a tree into position for processing (applies only to the single- or double-grip harvesters). Begins and ends with tire movement.

Move log: any activity required to move a felled log or straighten a bunch. It can occur at any time during the cycle.

Brush: any activity related to clearing obstructions such as regeneration, snags, unmerchantable stems, etc. It can occur at any time during the cycle.

Travel: time spent moving from one cutting area to another.

Delay: any interruption of normal work cycle lasting less than 15 minutes.

Skidding and Forwarding (grapple skidders and forwarders):

Travel empty: any travel from the log deck to logs in the block. Begins when skidder or forwarder begins moving toward bush after decking and ends when unit stops forward movement at bush loading site.

Position: any time related to positioning the skidder or forwarder for picking up logs in the bush. Begins and ends with tire movement.

Move-to-load: any time related to moving the skidder or forwarder to pickup additional logs. Begins and ends with tire movement.

Travel loaded: any travel from the bush to the decking area with a load of logs. Begins when skidder or forwarder begins forward movement and ends when the unit reaches the edge of the decking area, or drops the bunch outside the decking area.

Pull-bunch-into-landing: any time related to pulling bunches that were positioned outside the decking area from further away into the landing.

Delimb: any time related to delimbing logs, either with the skidder, waiting for buckermen to complete limbing and bucking, or waiting for the skidder or forwarder operator to limb logs.

Pile: any skidder or forwarder activity related to piling logs at the deck.

Clean landing: any activity related to clearing debris away from the landing area.

Delay: any interruption of normal work cycle lasting less than 15 minutes.

Mechanical **Delimbing**

Pick-up log: any activity associated with picking up a log from the log deck.

Delimb log: any activity related to removing limbs from the stem. Begins as the boom strokes the stem through the delimbing knives and ends when the top is cut, or the stem is put down.

Top log: any time related to severing the top of the tree from the stem.

Put-down log: any activity associated with placing the delimbed and topped log onto the log deck.

Nonmerchantable processing: any time related to handling a nonmerchantable or undersized piece.

Move: any carrier travel to reach a new delimbing position, excluding travel to another landing. Begins and ends with track movement.

Delay: any interruption of normal work cycle lasting less than 15 minutes.

APPENDIX V

Silvicultural Prescriptions

No detailed silvicultural prescriptions were prepared for any case studies, apart from Blue Ridge Treatment 1, as noted in the text. The following comments identify the basic silvicultural prescription used to develop the harvesting plans.

Control Blocks
The general silvicultural prescription prepared by Forestry Canada and the industry cooperators for all control blocks were similar: all control blocks were clearcut using feller-bunchers and grapple skidders. All conifer stems greater than 25-cm at the stump and all aspen trees were felled. Although no special protection measures were designated,thewhite spruce understory was not deliberately run over or knocked down.

After harvesting, the control blocks which qualify as coniferous land base (according to pre-1990 reforestation standards) by having merchantable spruce volumes greater than 50 m^3 per ha, would be treated using disc trenchers or drag scari.tiers, and then planted with suitable conifer seedlings to meet clearcut stocking standards. Competition from aspen and grass would be controlled using manual or mechanical treatments as required. The block would be managed as part of the conifer land base.

Treatment Blocks
All treatment blocks had the same general silvicultural prescription. Treatment was designed to protect understory spruce during the harvest of hardwood and coniferous overstory in rnixedwood stands. Treatment represented the frost harvest stage of the two-stage mixedwood harvesting and tending model described by Brace and Bella (1988) which provides for:

a) perpetuation of the mixedwood land base for a period as long as 60 years;

b) utilization of merchantable timber, mainly mature aspen, forestalling further losses to decay;

c) accepting surviving spruce understory within a broad range of density and distribution - often clumped - as the basis for the next spruce harvest in about 60 years. The spruce component of the stand should be enhanced over time by increased growth and yield of the released understory, and by natural seeding of spruce under aspen. This strategy reduces the costs and risks of spruce plantation establishment and management required if conversion to coniferous land base management were initiated, as is being done in controls.

d) accepting aspen seedling and sucker regeneration in areas not stocked with spruce, and only in-planting and tending those areas defined by survey to be understocked to either desirable hardwoods or conifers, such as landings.

e) a demonstration of timber production, wildlife habitat, and landscape aesthetics aspects of mixedwood land base management while retaining the option to convert to hardwood or coniferous land base management in the future.

Drayton Valley Treatment 1 and 2, and Hinton and Blue Ridge Treatment 1 Blocks

Drayton Valley Treatment land 2, Hinton Treatment l, and Blue Ridge Treatment 1 all had the same general silvicultural prescriptions noted above, and were logged using feller-bunchers and grapple skidders. On dry sites, all merchantable stems greater than 25-cm stump diameter were felled. The remaining stems provided shade to the site that would reduce soil temperatures and reduce aspen suckering. In addition, the spruce between 15 and 25 cm stump diameter provided a seed source for future regeneration. On moist sites, all merchantable stems greater than 15-cm stump diameter were felled, as larger stems would probably not be windfirm.

Merchantable stems located within dense clumps of white spruce understory were left standing if their removal resulted in excessive white spruce damage. All felling occurred off the skid trails, and feller-bunchers deposited bunches on or beside the skid trails. Feller-buncher travel, and all skidder travel, was restricted to designated trails. At Hinton Treatment 1 and Blue Ridge Treatment 1 blocks, rub stumps were left beside the skid trails and all trees were limbed and topped before they were skidded to landings.

Hinton and Blue Ridge Treatment 2 Blocks

Hinton Treatment 2 and Blue Ridge Treatment 2, had the same silvicultural prescription, and were harvested using Scandinavian equipment. All merchantable stems greater than 25-cm stump diameter were felled. The remaining stems provided shade to the site to reduce soil temperatures and thereby reduce aspen suckering. In addition, the spruce between 15 and 25 cm stump diameter provided a seed source for future regeneration. Merchantable stems located within dense clumps of white spruce understory were left standing if their removal would cause excessive white spruce damage.

Harvesters delimbed the stems so that limbs and tops were left on the harvester/forwarder trails. This provided a mat for the forwarder to travel over and reduced the chance for site disturbance. Forwarders travelled only along the same trails made by the harvesters.