Silvicultural and harvesting options to favor immature white spruce and aspen regeneration in boreal mixedwoods

S. Navratil, L.G. Brace, E.A. Sauder, and S. Lux

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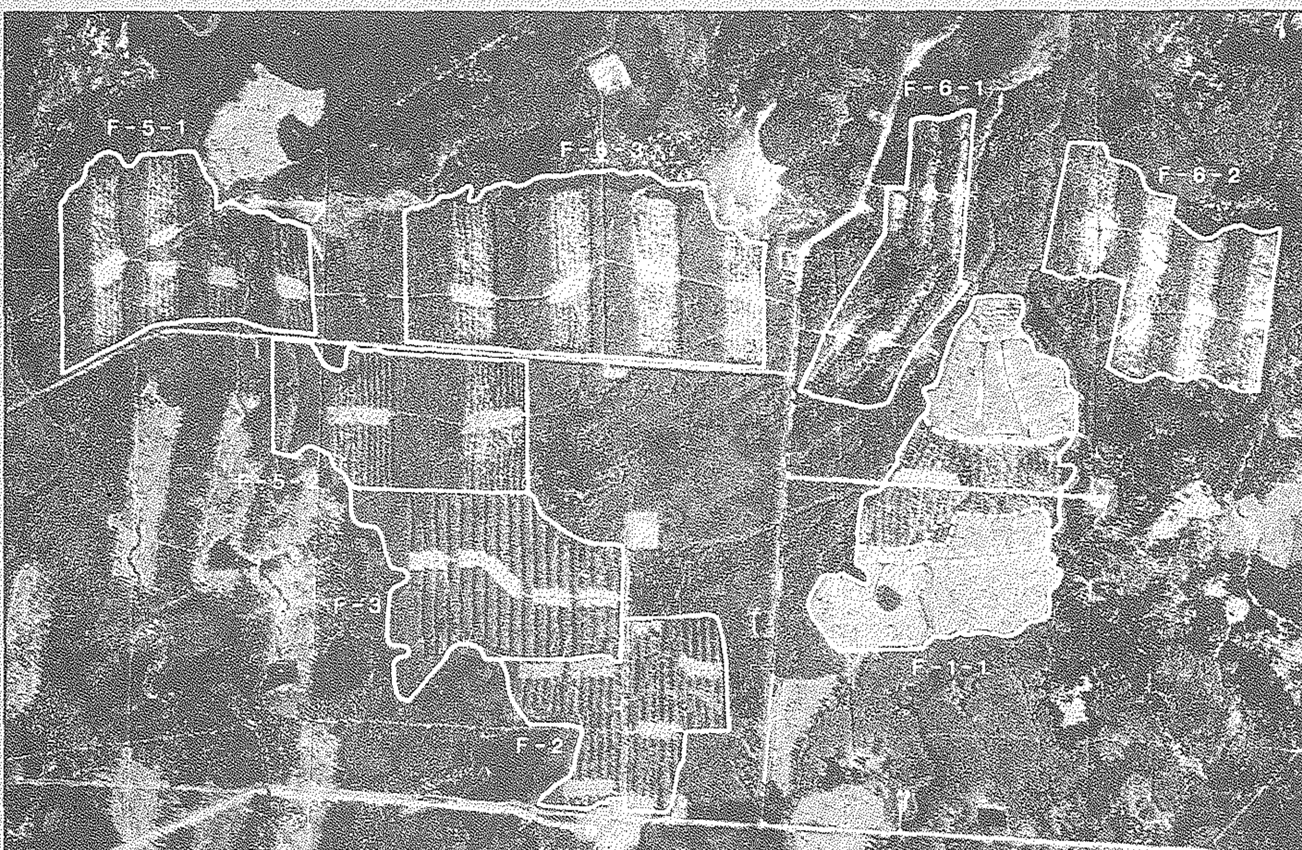

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Photo mosaic of Project 8032 provided by Alberta Environmental Protection, Resource Information Division.

SILVICULTURAL AND HARVESTING OPTIONS TO FAVOR IMMATURE WHITE SPRUCE AND ASPEN REGENERATION IN BOREAL MIXEDWOODS

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ABSTRACT

Two sequential projects were implemented in boreal mixedwoods in Alberta. Project 1480, initiated in 1988, tested the planning and application of silvicultural and harvesting systems designed to protect immature (understory) white spruce during the harvest of aspen overstory, realize the growth potential of residual spruce, and encourage aspen regeneration. Silvicultural prescriptions were based on a two-stage harvesting and tending stand level model. Results show that, using conventional harvesting equipment, and with adequate planning, crew training, and supervision, 50–60% of spruce understory trees can be protected during the harvest of overstory deciduous trees; most wind damage will occur in the first 3 post-harvest years. Five years after the first-stage harvest, spruce growth shows significant height, diameter, and volume response, and aspen regeneration is adequate. The potential yield in 60 years from a second harvest of spruce and aspen seems promising. Project 8032, initiated in 1992, tested the effectiveness of a range of silvicultural and harvesting systems in reducing wind damage to residual spruce on moist-to-wet sites after harvest of the deciduous overstory. The project includes studies of harvesting costs, productivity, mixedwood growth and yield, aspen regeneration, wind damage, and wind behavior within cutblocks. Initial results show that the silvicultural systems and cutblock designs implemented provide a range of residual spruce wind protection and that, using conventional roadside equipment, a variety of silvicultural options can be achieved.

RÉSUMÉ

Deux projets séquentiels ont été entrepris dans les forêts boréales mixtes de l'Alberta. Le projet 1480, commencé en 1988, a permis de faire des expériences de planification et d'application sur les systèmes de sylviculture et d'exploitation ayant pour but de protéger les peuplements immatures (sous-étage) d'épinettes blanches au cours de l'exploitation de l'étage dominant composé de trembles, de comprendre le potentiel de croissance des épinettes résiduelles, et de favoriser la régénération des trembles. Les ordonnances sylvicoles reposent sur un modèle d'exploitation et de niveau de soin des peuplements en deux étapes. Les résultats nous indiquent qu'en utilisant des pièces d'équipement d'exploitation conventionnels, et avec une planification adéquate, à l'aide d'équipes de travail bien formées et supervisées, entre 50 et 60 pour-cent du sous-étage d'épinettes peut être protégé pendant l'abattage de l'étage dominant de feuillus; la plupart des dommages causés par le vent surviennent pendant les trois prochains mois suivant l'abattage. Cinq ans après la première étape de la coupe, les épinettes croissent de manière significative en hauteur, en diamètre et en volume, et les trembles repoussent de manière adéquate. Les possibilités d'une deuxième récolte d'épinettes et de trembles dans 60 ans semblent encourageantes. Le projet 8032 commencé en 1992, avait pour but de vérifier l'efficacité de toute une gamme de systèmes de sylviculture et d'exploitation pour réduire les dommages causés par le vent aux épinettes résiduelles en terrains allant d'humides à détrempés après la coupe de l'étage dominant de feuillus. Le projet a examiné les coûts d'exploitation, la productivité, la croissance et le rendement de la forêt mixte, la régénération des trembles, les dommages causés par le vent, et le comportement du vent dans divers terrains de coupe. Les résultats préliminaires démontrent que les systèmes de sylviculture et la configuration des terrains de coupe fournissent la protection contre le vent nécessaire aux épinettes résiduelles, ils indiquent aussi que plusieurs options sont possibles en utilisant des pièces d'équipement conventionnels.

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The exclusion of certain manufactured products does not necessarily imply disapproval nor does the mention of other products imply endorsement by the Canadian Forest Service.

Regional Mixedwood Resource

Boreal mixedwoods occupy about 150 000 km^2, or one-third of the productive forest land base of the prairie provinces and northeastern B.C., distributed within four regional forest sections (Rowe 1972) as shown in Figure 1. This report focuses on white spruce (*Picea glauca* [Moench] Voss) occurring as an understory with aspen (*Populus tremuloides* [Michx.]), balsam poplar (*Populus balsamifera* L.) and white birch (*Betula papyrifera* Marsh.). Emphasis is placed on planning and applying innovative silvicultural and harvesting techniques that protect immature (understory) white spruce during the harvest of deciduous overstories; provide post-harvest wind protection and realize the growth potential of residual spruce; and encourage natural regeneration of deciduous species in stand openings created by harvest.

Silvicultural and Management Considerations

Conventional inventory information on the nature and extent of spruce understory stands is generally not reliable. Steneker (1967) reported about 30% of deciduous–coniferous mixedwoods in Manitoba–Saskatchewan with significant spruce understories, and recent surveys in Alberta have shown similar amounts in stands currently inventoried H (hardwood) and HS (hardwood–softwood). They tend to occur as a continuum, rather than in clearly recognizable associations, owing to fire and utilization history, site patterns, and species ecology.

In the long run, supplies of commercial white spruce depend upon successful establishment of new stands. To date, this has proved to be relatively

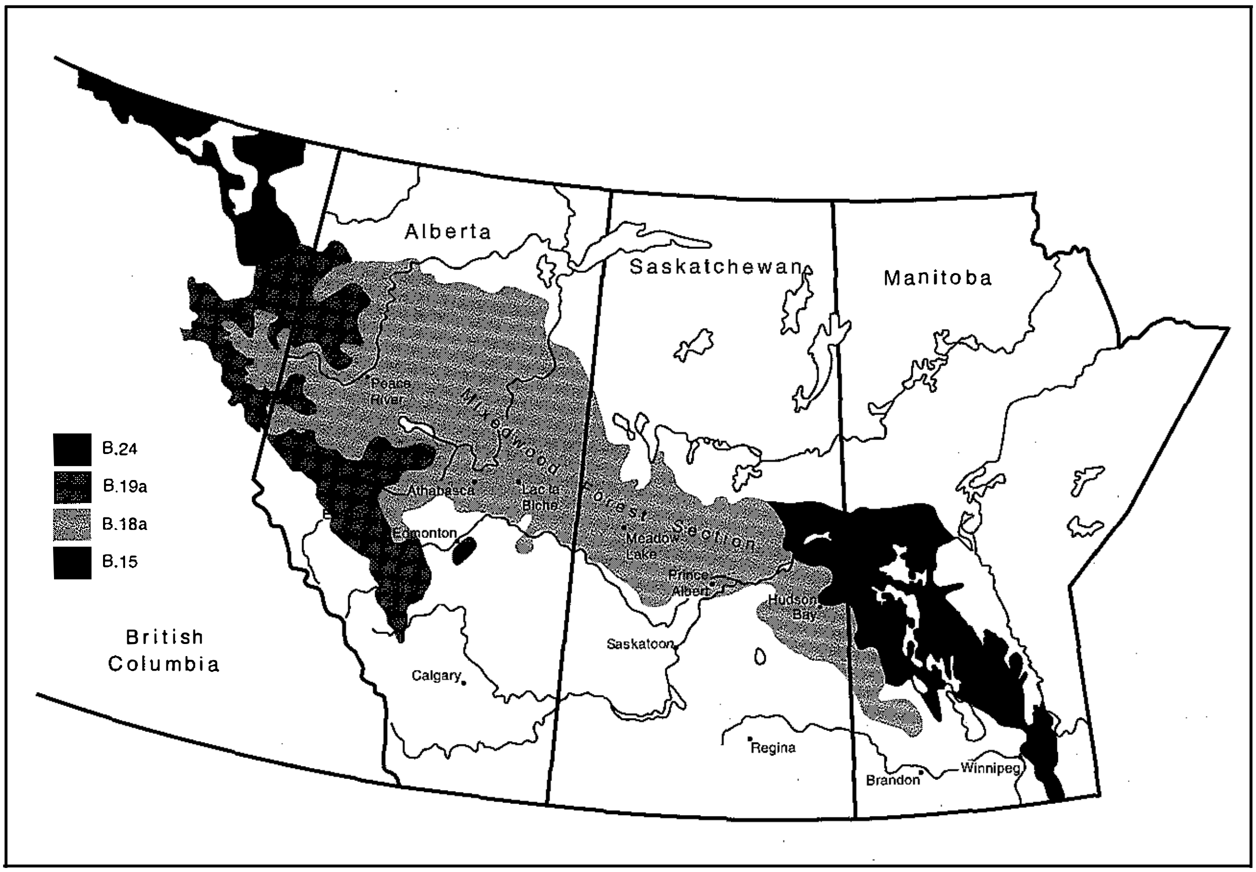

Figure 1. Boreal mixedwood distribution in western Canada (Rowe 1972).

costly and ineffective on mixedwood sites (Henderson 1988; Peterson 1989), even though it has been the subject of considerable regional research for many decades (Jarvis et al. 1966). Within the next 30 to 50 years, spruce that have developed to commercial size through natural succession under the protection of hardwoods will be a significant source of spruce timber in boreal mixedwoods. However, the demand for aspen, which accounts for 80% of regional hardwoods, is rising dramatically, particularly in Alberta and Saskatchewan (Canadian Council of Forest Ministers 1993; Cheyne 1994) where more than 50% of the aspen annual allowable cut (AAC) has been committed for new development (Table 1). Approximately 80% of stands inventoried as H and HS in Alberta are currently more than 60 years of age (Fig. 2) and many are now being scheduled for aspen harvest using conventional harvesting equipment and procedures, without adequate recognition of the importance of associated spruce understory to the future softwood timber supply.

From a conifer timber management perspective, the value of spruce understory depends on the cost and effectiveness of protection during the harvest, post-harvest density, distribution and windfirmness, and relative growth rates after release. If released understory meets conifer establishment and performance standards without additional planting and tending costs, its value could exceed $2000/ha—the approximate cost of establishing and tending a spruce plantation on a mixedwood site to age 30 (Navratil et al. 1989). In most cases, the value of protected understory will be considerably less, declining as post-harvest density and distribution depart from the ideal. At some point it will no longer have economic value for conifer timber production alone.

A broadened mixedwood management perspective could recognize a wider range of acceptable coniferous and deciduous regeneration, stocking, growth, and yield, placing understory spruce protection within the context of extensive mixedwood ecosystem management. There is potential for affordable, ecologically sound strategies compatible with current priorities on alternatives to clear-cutting, maintenance of biodiversity, and long-term sustainability of boreal ecosystems.

Peterson et al. (1989), in interviews with regional mixedwood foresters in industry, government, and research, found that they recognized mixedwoods as a well-adapted ecological mix of species, but are puzzled by the complexity of the management problems posed by such ecosystems, one aspect of which is understory protection, which was given a high-priority rating.

While the debate over boreal mixedwood ecosystems management continues, forest industry and provincial land managers in western Canada are being challenged to modify and adapt harvesting systems that protect white spruce understories while removing aspen, and to move toward mixedwood land base management. This poses problems that have implications for policy and regulations about land tenure, stocking and performance standards, and operational ground rules. It also raises questions about technical feasibility, costs, and mixedwood growth and yield (Samoil 1988).

Table 1. Utilization trends and current annual allowable cut of aspen in western Canada (million m³)

Province	Utilization trends[a]					Current total AAC[b,c]	% AAC committed 1994 (est.)
	1978	1983	1988	1992	1994		
Manitoba	0.02	0.02	0.04	0.12	0.12	2.7	4.4
Saskatchewan	0.45	0.26	0.43	1.40	1.56	3.0	52.0
Alberta	0.10	0.21	1.53	3.09	5.39	10.4	51.8
B.C. (northeast)	–[d]	–	0.16	–	0.96	3.5	27.4

[a] From Canadian Council of Forest Ministers (1993).
[b] AAC = annual allowable cut.
[c] From Cheyne (1994) using estimates of rated mill capacity.
[d] Not available.

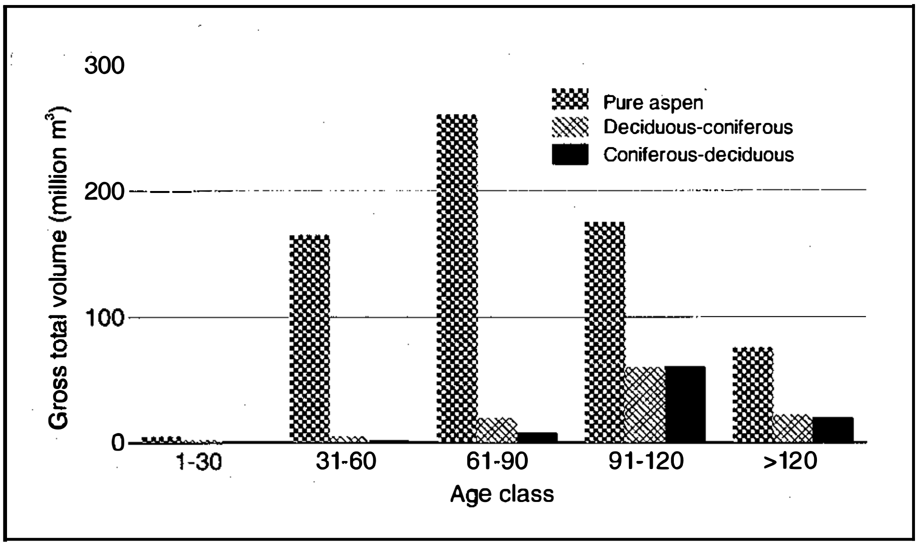

Figure 2. Gross total volume of aspen and other poplar in hardwood and mixedwood stands in Alberta, 1987 (Ondro 1989).

Increases in hardwood utilization, coupled with public demand to maintain mixedwoods for a variety of non-timber purposes, are challenging the traditional conifer bias in mixedwood management. This requires management objectives that go beyond conifer silviculture and growth and yield. It also creates the need for an ecosystem-based approach to both management planning and operations in mixedwoods. Projects 1480 and 8032 address these issues.

Two-Stage Harvesting and Tending Model

A two-stage harvesting and tending stand-level model, described by Brace and Bella (1988), was adopted as the basis for silvicultural prescriptions on which Project 1480 treatments and some Project 8032 treatments described in this report were based. Figure 3 illustrates the model, which has been designed to accommodate two harvests of aspen in a 120-year cycle and to realize the yield potential of associated understory spruce.

To illustrate the process, assume a first harvest at year 60, when aspen are aged 60 and understory spruce average 40 years of age. The aspen and all spruce over 25 cm dbh could be harvested, leaving a released spruce understory. Following harvest, aspen and poplar suckers and seedlings will regenerate in the available spaces, resulting in a stand comprising separate species clumps as well as intermixed hardwoods and conifers. Conifers could be planted in areas found by survey to be inadequately stocked with acceptable conifers or hardwoods. Both planted and naturally regenerated conifers could be tended as needed to maintain growth rates. This would result in perpetuation of a mixedwood stand for the period necessary for a new hardwood crop and the released spruce to mature, possibly by year 120. During this time spruce could seed in under the aspen, assuming a seed source is maintained, particularly if the site is scarified purposely or by logging activity. Seed could originate from adjacent stands, from seed-trees purposely left during harvest, and from the larger protected understory that will bear seed in the future. When the second harvest is taken at age 120, options for managing the stand as either mixedwood, hardwood, or conifer could be exercised. Navratil et al. (1989) described some of the silvicultural challenges posed by these options.

Advantages of the model could include:

- reduction or avoidance of the costs and risks associated with establishing and growing spruce plantations on mixedwood cutovers;
- improved utilization of aspen, and increased spruce AAC both through increased growth and through shorter rotations for spruce released from overstory suppression;
- demonstration of the maintenance of mixedwood landscape aesthetics, wildlife habitat, recreational values and biodiversity, thereby addressing major shortcomings of the clear-cutting system as now practiced on many mixedwood sites; and
- contributions to solving the problems created where hardwood and conifer harvesting rights are held by different companies on the same land

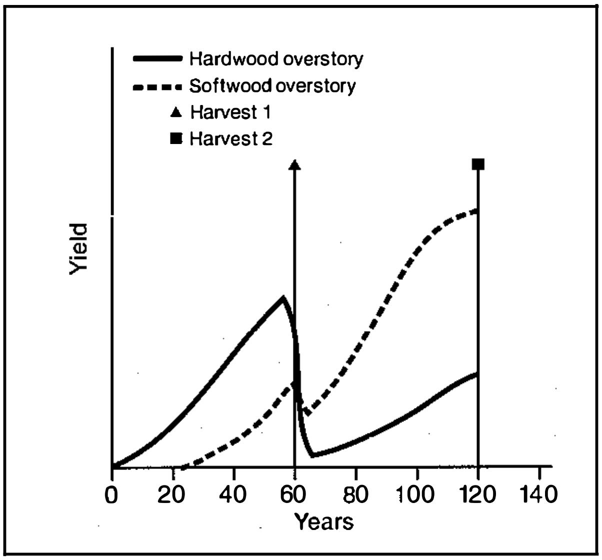

Figure 3. Generalized two-stage harvesting and tending model (values are relative).

base, and where protection of understory spruce is a priority for the softwood user.

Some of the disadvantages of the model could include:

- uncertainty about the feasibility of adapting available harvesting technology to protect understory across a range of stand age, density, and site conditions;
- potential for windthrow of released spruce, particularly on moist sites, as well as the risk of leader-weevil infestations in released spruce; and
- problems with defining mixedwood regeneration standards, and estimating the growth and yield of mixed-species stands of released spruce and new aspen suckers.

The two-stage model is a potential option for mixedwood stands in which aspen are of usable size and quality, understory density and distribution is suitable, and risk of blowdown and other damage is acceptable or controlled by harvest strategy. Mixedwood stands in which aspen are either too young or too old and decadent to be viable for timber harvest, or where understories are deemed more valuable than overstories, require other management approaches (Navratil et al. 1989).

The two-stage model was applied and tested in Alberta in two sequential projects, both funded by Canada–Alberta agreements, as follows:

1. Project 1480. Protecting white spruce understories when harvesting aspen. Canada–Alberta Forest Resource Development Agreement (FRDA), 1985–90.

2. Project 8032. Silvicultural and harvesting options to favor immature white spruce and aspen regeneration in boreal mixedwoods. Canada–Alberta Partnership Agreement in Forestry (PAIF), 1991–95.

Previous reports for Project 1480 include those by Brace (1992) and Sauder (1992, 1993). This report describes 5-year results for Project 1480, and planning and establishment detail and some initial results for Project 8032.

PROJECT 1480, BACKGROUND

Planning and Objectives

Project 1480 was a cooperative study initiated in 1988 under the Canada–Alberta FRDA program, involving the Canadian Forest Service, the Alberta Land and Forest Services, Weyerhaeuser Canada Ltd., Weldwood of Canada Limited, Blueridge Lumber (1981) Ltd., Millar-Western Industries Ltd., and the Forest Engineering Research Institute of Canada (FERIC). Cooperators were members of a steering committee which set block selection criteria, prescreened candidate areas, and set harvesting objectives.

Three mixedwood study sites (Fig. 4) were selected in central Alberta: the first, west of Drayton Valley; the second, northeast of Hinton; and the third, northeast of Whitecourt. Each site consisted of 50-60 ha containing relatively uniform terrain. Treatments were not replicated within study sites. They were established and analyzed in a case study format with a strong operational bias. FRDA funding provided for a 5 year assessment period. Supplemental funding would be necessary to obtain reliable longer-term growth and yield results.

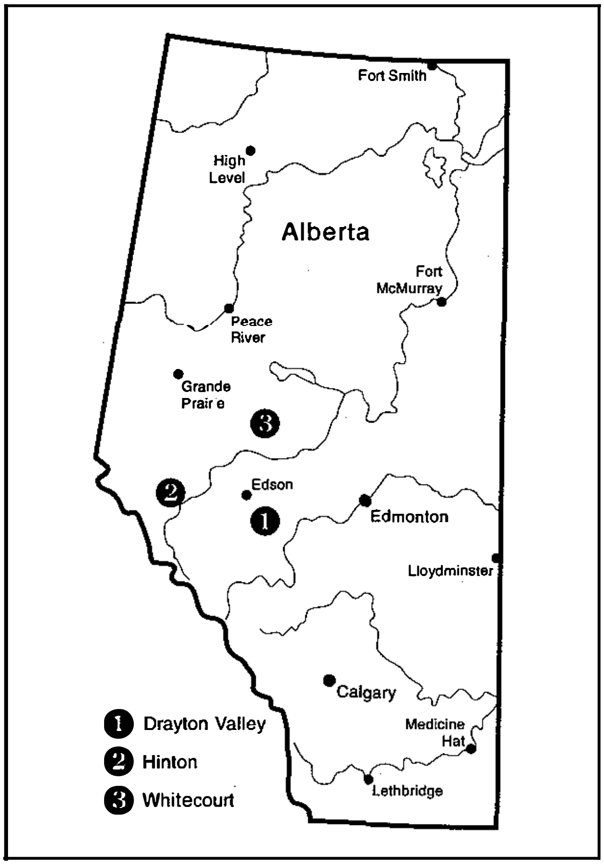

Figure 4. Project 1480 location of study stands.

Each study site was divided into three blocks: one control where conventional harvesting practices were employed and understory was not deliberately protected, and two treatment blocks where understory was protected.

Objectives for Project 1480 were to:

- assess damage to understory spruce trees released during harvesting of the aspen overstory in each block;
- monitor subsequent growth and windthrow of the residual spruce, and density and growth of new aspen and poplar regeneration;
- assess harvesting productivity and costs for each block; and
- demonstrate the role of understory protection in addressing landscape aesthetics and wildlife habitat concerns, in an integrated resource management (IRM) context.

Treatment prescriptions were planned to satisfy the first stage of the two-stage harvesting and tending model described previously. Treatments were designed to protect understory spruce during the harvest of hardwood and coniferous overstory. Even though some of these stands, notably Hinton Treatment 1 and Drayton Valley Treatments 1 and 2, would not qualify under Alberta's 1991 reforestation standards as coniferous land base, because they had less than 50 m^3/ha merchantable spruce, they had significant amounts of understory which was expected to survive harvest (Table 2). It was assumed that all stands except controls would subsequently be managed as mixedwoods, without reference to current conifer regeneration and land base management policies and regulations, and that data collected from the study would serve as input to evolving mixedwood management strategies. Prescriptions are described in detail by Brace (1992). The treatments were also designed to test the influence of different harvesting equipment, operational practices, and levels of planning and supervision on the amount of understory left undamaged after harvesting.

Control prescriptions were all conventional clearcuts harvested using feller-bunchers and grapple skidders with no special protection measures designated for white spruce understory. Most control blocks had at least 50 m^3/ha of merchantable coniferous timber, and it was expected that the understory component would be destroyed during harvest. They were assumed to qualify under current policies and regulations for management as coniferous land base after harvest. They would subsequently be treated using appropriate scarification, and planted with suitable white spruce seedlings to meet provincial stocking standards. Competition from aspen and grass would be controlled as required. Each block would continue to be managed as part of the coniferous land base.

Harvesting prescriptions shown in Table 3 were devised to achieve silvicultural treatment prescriptions, and are described in detail by Sauder (1992).

Pre-Harvest Sampling and Remeasurement Surveys

Each block was sampled before harvest using a systematic grid to achieve Alberta Land and Forest Services "full density" regeneration survey standards of approximately 84 plots (1.8 m radius) per block. Every second 1.8 m radius plot had a 6 m radius plot superimposed for collection of block inventory data including detailed height and

Table 2. Summary of Project 1480 pre-harvest statistics for stands inventoried in 1988

Area/ Treatment	Location	Stand age[a] (yr)	Stand size (ha)	No. plots/ plot diameter 6 m	No. plots/ plot diameter 1.8 m	Stocking[b] (%)	Total volume (m^3/ha) Aspen	Total volume (m^3/ha) Poplar	Total volume (m^3/ha) White spruce	Total volume (m^3/ha) Total[c]	Merch. volume[d] white spruce (m^3/ha)	No. spruce stems/ha by height class (m) 0.5–2.4	2.5–14.0	>14.0	Total[e]
Whitecourt															
Control	NW4-62-10-W5	>100	9.4	43	85	36	335	12	86	433.7	82	253	177	109	538
Treatment 1	NW4-62-10-W5	>100	28.0	64	129	45	280	31	83	408.1	77	657	428	98	1184
Treatment 2	NW9-61-10-W5	>70	15.0	38	76	49	160	25	82	271.5	70	535	578	65	1178
Hinton															
Control	NW22-52-24-W5	>70	18.1	41	85	72	191	36	74	313.6	49	2158	1744	71	3973
Treatment 1	NW22-52-24-W5	>70	14.1	44	88	44	246	21	16	282.9	5	511	793	9	1313
Treatment 2	NW22-52-24-W5	>70	17.8	32	70	76	146	37	66	254.9	45	1917	1991	39	3947
Drayton Valley															
Control	SE26-48-12-W5	>110	20.0	43	86	41	114	70	46	293.0	37	278	569	27	874
Treatment 1	SE26-48-12-W5	>110	20.0	43	87	39	170	47	31	252.4	25	288	405	14	707
Treatment 2	SE31-48-11-W5	>110	15.0	36	78	22	157	34	12	232.9	8	106	312	42	459

[a] Age of aspen.

[b] Spruce >0.5 m.

[c] Includes all species, derived using local height diameter curves and volume equations for Volume Region 4 (Alberta Energy and Natural Resources 1985).

[d] Merchantable volume, applying utilization standard 15/10 (Alberta Energy and Natural Resources 1985).

[e] Totals may not add up due to rounding.

Table 3. Summary of harvesting prescriptions

Prescription	All control	Drayton Valley		Hinton		Whitecourt	
		Treatment 1	Treatment 2	Treatment 1	Treatment 2	Treatment 1	Treatment 2
Pre-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 protection	Protected	Protected	Protected	Protected	Protected	Protected
Harvest operations supervision	Minimal	Minimal	Minimal	Continuous daily supervision	Contractor self-supervised	Continuous daily supervision	Operators self-supervised
Roading 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 all crew	Piece rate ($\$/m^3$) for all crew	Hourly rate for all crew	Piece rate ($\$/m^3$) for all crew	Hourly rate for all crew	Piece rate ($\$/m^3$) for all crew
Equipment							
Felling	As for Treatment 1 in the respective study area	Aspen felled with shear-equipped front-end loader feller-buncher. Conifer hand felled.	Aspen and conifer felled with shear-equipped front-end loader feller-buncher	Aspen 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 14-t forwarders
Limbing	Drayton Valley: as for Drayton Valley Treatment 1; Hinton and Blue Ridge: aspen and conifer delimbed at roadside landing with stoke delimber	Aspen manually delimbed at landing. Conifer delimbed at landing using skidder blade.	Aspen and conifer stems rough delimbed and topped either at the site, or prior to the bunches entering the landing area	Aspen and conifer manually rough delimbed and topped at felling site and stoke delimbed 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 2.6-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 cut to tree-length at roadside.	Aspen cut to 2.6-m length at felling site. Conifer cut 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.

Source: Sauder (1992).

diameter data for understory spruce 0.5 m and taller. Pre-harvest block statistics are shown in Table 2. Pre-harvest composition, density, distribution, and merchantable volume of overstory species were considered representative of regional mixed-woods aged 70–110 years on mesic sites. Understory densities covered the range of 250 to 1000 stems/ha between 0.5 and 14 m tall. Height and distribution patterns—especially clumpiness—were considered characteristics of regional understories. Spruce understories averaged 50 years of age and ranged widely. Most spruce were less than 70 years old and capable of responding to release (Johnson 1986).

Remeasurements for logging damage and of post-harvest stocking levels for understory spruce were completed one year after harvest. Remeasurements of wind damage to understory spruce were completed 1, 2, and 5 years after harvest. All were taken on 6 m radius plots.

Remeasurement of understory spruce height, diameter, and mortality were completed on 6 m radius plots one and four growing seasons after harvest for Hinton and Whitecourt blocks, and one and five growing seasons after harvest on Drayton Valley blocks.

Aspen and poplar regeneration was assessed on 1.8 m radius plots one and four growing seasons after harvest for Hinton and Whitecourt, and one and five growing seasons after harvest for Drayton Valley.

PROJECT 1480, PRELIMINARY RESULTS

Harvesting Prescriptions

The overall harvesting prescriptions for Project 1480 were designed to determine what harvesting phases and activities were most damaging to immature spruce stems, and to determine whether the number of immature spruce stems left standing after harvesting could be increased through more intensive planning and supervision, and through changes in the operating procedures (Sauder 1992). Study participants wanted to understand the limitations of the roadside harvesting system before looking at alternatives such as the cut-to-length system. As a result, the harvesting equipment focused predominantly on feller-bunchers and grapple skidders, and to a lesser extent on Scandinavian harvesters and forwarders. Harvesting operations were originally specified to be conducted while temperatures were above –15°C to minimize the potential for breaking frozen, fragile immature spruce stems during harvesting. However, during the harvesting trials, operations were successfully conducted during even colder periods.

A variety of harvesting machines were used during the harvesting trials. Although the excavator–carrier mounted feller-buncher was and still is the most popular felling unit in central Alberta, at the time of the study several crawler front-end loaders were equipped with feller-buncher attachments. One of these units was selected for study at Drayton Valley because the buncher had a narrow machine width that made it maneuverable in confined spaces. The unit was also equipped with a shear-type cutting device, which causes unacceptable butt-splitting in conifer sawlogs. As a result, the Drayton Valley contractor hand-felled all conifers on the control and Treatment 1 blocks. However, the mill allowed the contractor to mechanically fell the conifers on Treatment 2 to demonstrate the advantages of mechanically felling and bunching all stems. During the harvesting trials, only two Scandinavian harvesters were available in Alberta, and both were based out of Whitecourt. They were tested in both the Whitecourt and Hinton studies. 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.

Harvesting Damage and Post-Harvest Stand Conditions

Field observations suggest that the amount of immature spruce protected is influenced by the pre-harvest density of immature spruce, equipment design, equipment operating techniques, work practices of the crew, and levels of supervision and planning.

To assist in determining the impact of different equipment, and different levels of planning, supervision, and operating practices on post-harvest understory damage, harvest operations were classified into three groups according to the level of protection afforded understory stems during harvesting. The understory damage and equipment productivity data from the control blocks (no protection) was to be the baseline information for comparison of the treatment blocks. However, only the Hinton and Whitecourt control blocks could be used for the final comparison because the Drayton Valley control block was not harvested to control block specifications. The crew protected the understory as if it were a treatment block. The three Drayton Valley sites and Whitecourt Treatment 2 all had an intermediate level of understory protection because crew commitment to understory protection was high, even though pre-harvest planning and on-site supervision were minimal. Hinton Treatments 1 and 2, and Whitecourt Treatment 1 sites were all considered high levels of understory protection because, in addition to a well-motivated crew, pre-harvest planning was extensive, on-site supervision was present throughout harvesting, and the crew undertook special practices to reduce understory damage.

Table 4 summarizes pre- and post-harvest stand conditions. Clear-cut harvesting on the control block, where no attention was given to the protection of immature spruce, resulted in 2–16% of the immature spruce stems being left undamaged after harvesting. A relatively high level of immature spruce protection (16%) occurred in the Hinton control block because the immature spruce was located in dense stands that restricted equipment entry. In addition, the company left marginally merchantable stems standing if they were surrounded by immature spruce stems. On blocks where conventional feller-bunchers and grapple skidders used special operating practices to reduce damage to immature spruce stems, 40–61% of the immature spruce stems were protected from harvest damage. However, with the cut-to-length harvesting equipment, only 21–30% of the immature spruce stems were left undamaged.

The extraction phase destroyed and injured more immature spruce residuals than the felling phase (Table 5). Most destruction occurred during the construction of extraction trails by the feller-buncher, mainly due to the large size of the machines. Most injuries occurred alongside extraction trails during the skidding phase of extraction, and by skidders traveling off designated trails.

Table 4. Summary of understory trees, 2.5–14 m high, before and after harvesting

Block	Pre-harvest trees (no./ha)	Undamaged post-harvest trees	
		No./ha	%
No understory protection			
Roadside equipment			
Hinton: Control	1744	278	16
Whitecourt: Control	177	4	2
Intermediate level of understory protection			
Roadside equipment			
Drayton Valley: Control	569	226	40
Drayton Valley: Treatment 1	405	171	42
Drayton Valley: Treatment 2	312	189	61
Cut-to-length equipment			
Whitecourt: Treatment 2	578	119	21
High level of understory protection			
Roadside equipment			
Hinton: Treatment 1	793	416	52
Whitecourt: Treatment 1	428	260	61
Cut-to-length equipment			
Hinton: Treatment 2	1991	591	30

Source: Brace (1992), from pre- and post-harvesting data collected for Forestry Canada, Northern Forestry Centre; unpublished.

Table 5. Summary of understory trees, 2.5–14 m high, damaged during harvesting (%)

Block	Felling		Extraction		Harvested	Blowdown	Undamaged
	Injured	Destroyed	Injured	Destroyed			
No understory protection							
Roadside equipment							
Hinton: Control	6	2	24	50	2	0	16
Whitecourt: Control	0	10	7	74	7	0	2
Intermediate level of understory protection							
Roadside equipment							
Drayton Valley: Control	10	1	20	24	5	0	40
Drayton Valley: Treatment 1	15	0	15	25	2	0	42[a]
Drayton Valley: Treatment 2	9	1	17	13	1	0	61[a]
Cut-to-length equipment							
Whitecourt: Treatment 2	30	3	21	15	9	2	21[a]
High level of understory protection							
Roadside equipment							
Hinton: Treatment 1	13	1	16	17	1	0	52
Whitecourt: Treatment 1	8	0	6	21	4	0	61
Cut-to-length equipment							
Hinton: Treatment 2	24	3	28	14	1	0	30

Source: Brace (1992), from pre- and post-harvesting data collected for Forestry Canada, Northern Forestry Centre; unpublished.

[a] Numbers may not add up due to rounding.

Extraction-related destruction and injury were reduced by minimizing the number of extraction trails constructed, confining skidders to designated trails, and leaving rub-posts alongside trails.

During felling of treatment blocks some immature residual spruce were injured but relatively few were destroyed. Felling injuries increased as immature spruce densities increased and were caused by the felling head itself, by lack of directional control of the falling stem, or by broken stems falling into the immature spruce during felling. Felling-related injury and destruction were reduced by use of the feller-buncher to lift and carry severed stems and placing them on the ground in a controlled fashion thus avoiding contact with immature residual spruce.

At Drayton Valley, both the interest of the crew in protecting the immature spruce stems on the treatment blocks and the clumpy nature of the immature spruce contributed to the high proportion of undamaged residuals. Damage to the immature spruce stems was reduced at the bunch assembly points and along the trails when both aspen and conifer bunches were delimbed before skidding (especially on Treatment 2 at Hinton and Whitecourt). High stumps left beside the trail as rub-posts were also effective in deflecting stems around trailside immature spruce stems.

The processing method and the location of landings and log decks also contributed to the level of immature spruce stems protected. The greater the area occupied by landings and log decks, the greater the potential to clear off immature spruce stems occupying the site. At Drayton Valley, stems were manually bucked into bolts at the landing and high log decks could not be built. In addition, because there were a number of subcontractors working for the contractor, separate log deck areas were required to ensure subcontractors received the correct payment for the volume of wood they skidded and bucked. Although bolts were trucked out of the landings at regular intervals during harvesting, additional log storage space was required when hauling was delayed because of loader breakdowns or soft road conditions.

Mechanical processing of stems generally increased the height of log decks. Decking areas at Hinton and at Whitecourt Treatment 2 were further reduced because they were mostly located on the road right-of-way beside the main haul road.

At Whitecourt Treatment 1, log hauling could not occur until well after harvesting was completed. To minimize the amount of area occupied by decked logs, a hydraulic log loader restacked delimbed logs.

Equipment Productivity

FERIC collected harvesting production data in two ways. Shift-level production was determined using Servis recorder charts, machine piece counts, and references from the researcher's diary. In addition, work sample studies provided details of felling and skidding work cycles.

Generally, feller-buncher and grapple skidder productivity decreased as protection levels increased. Table 6 summarizes productivity of the felling equipment. Compared to felling on the control blocks, felling time per tree increased 30% at Drayton Valley, 14% at Hinton, and 44% at Whitecourt Treatment 1 blocks. In each case, the feller-buncher had to spend more time moving to bunch a stem and more time traveling between work sites. At Drayton Valley, felling time per tree also increased because the buncher had to travel around larger conifer stems left for hand felling. Felling time per tree at Drayton Valley Treatment 2 was less than on the control block because the buncher felled both deciduous and conifer stems.

At Hinton the harvester spent more felling time per tree because the stand was denser. More time was required to position both the machine and the felling head than at Whitecourt where the stand was more open. In addition, more time was required to process the stems at Hinton, where the stems were cut into 2.6 m lengths, than at Whitecourt where stems were cut into 3.4 to 7.1 m lengths.

Overall, availability and utilization of equipment were better on the treatment blocks than on the control blocks because more supervision ensured that felling equipment was in good mechanical order and that it was kept operating.

Table 7 summarizes productivity of the extraction equipment. At Drayton Valley, the skidding cycle time was much longer than at other blocks where skidders were used because the skidders had to wait for the bunches to be delimbed and bucked manually before decking. At Hinton and Whitecourt Treatment 1 blocks, skidding time per cycle increased because the designated skid-trails took a longer, more circuitous route to the landing. The

Table 6. Summary of felling equipment productivity

Block	Volume/ aspen tree[a] (m³)	No. trees[b]/ PMH[c]	Minimum time/tree (min)	Equipment Availability (%)	Equipment Utilization (%)	Volume[d]/SMH[e] (m³)
No understory protection						
Roadside equipment						
Hinton: Control	0.20	120	0.50	81	64	20
Whitecourt: Control	0.75	119	0.50	52	50	22
Intermediate level of understory protection						
Roadside equipment						
Drayton Valley: Control	0.80	114	0.53	63	57	39
Drayton Valley: Treatment 1	0.69	87	0.69	81	62	43
Drayton Valley: Treatment 2	0.54	119	0.50	77	70	37
Cut-to-length equipment						
Whitecourt: Treatment 2	0.13	59	1.03	87	81	8
High level of understory protection						
Roadside equipment						
Hinton: Treatment 1	0.20	104	0.57	89	77	18
Whitecourt: Treatment 1	0.85	82	0.72	86	78	17
Cut-to-length equipment						
Hinton: Treatment 2	0.29	32	1.89	85	77	8

[a] Characterizes the majority of stems in the block harvested.

[b] The unit of production varied with harvest system. Roadside equipment (feller-bunchers) produced full-length stems. Cut-to-length equipment produced logs.

[c] PMH = productive machine hour.

[d] Includes volume of both aspen and conifer pieces.

[e] SMH = scheduled machine hour.

Table 7. Summary of extraction equipment productivity

Block	Minimum cycle (min)	Equipment (%)		No. stems/ bunch	No. pieces[a]/ PMH[b]	Travel loaded			Volume[c]/ SMH[d] (m^3)
		Availability	Utilization			Distance (m)	Time (min)	Speed (min/100 m)	
No understory protection									
Roadside equipment									
Hinton: Control	5.21	92	65	9	107	100	1.40	1.40	15
Whitecourt: Control	4.21	96	94	5	69	70	1.33	1.90	23
Intermediate level of understory protection									
Roadside equipment									
Drayton Valley: Control	9.23	84	72	3	20	95	1.87	1.97	9
Drayton Valley: Treatment 1	10.26	85	68	4	24	130	1.94	1.49	11
Drayton Valley: Treatment 2	11.61	87	73	5	24	130	1.51	1.51	9
Cut-to-length equipment									
Whitecourt: Treatment 2	63.01	91	148	148	141	190	9.31	4.90	9
High level of understory protection									
Roadside equipment									
Hinton: Treatment 1	6.07	92	78	8	82	190	1.83	0.96	21
Whitecourt: Treatment 1	5.48	94	86	3	35	120	1.85	1.54	11
Cut-to-length equipment									
Hinton: Treatment 2	43.04	86	79	96	132	250	2.38	2.55	8

[a] The unit of production varied for each harvest system: roadside equipment (grapple skidders) dragged full-length stems to a landing or decking area, and the cut-to-length equipment (forwarders) carried manufactured logs to roadside.

[b] PMH = productive machine hour.

[c] Includes volume of both aspen and conifer pieces.

[d] SMH = scheduled machine hour.

cycle time of the forwarder at Whitecourt was longer than at Hinton because the travel distance was further and more logs were loaded and unloaded in each cycle.

At Drayton Valley, the number of stems per bunch increased because the buncher operator had less room to deck stems and therefore built larger bunches. At Hinton and Whitecourt, the buncher operators built smaller bunches on the treatment blocks. The buncher carriers were unstable when carrying large stems and as a result the operators were comfortable only when traveling short distances to bunching locations.

Although skidder productivity was reduced by the greater travel distances on blocks with designated skid-trails, study results show the time spent traveling did not increase proportionately to the travel distance. Both empty and loaded travel speeds of the grapple skidder increased because the skidders kept to one trail that gradually improved with use. Forwarder travel at Whitecourt was more difficult than at Hinton because the ground was softer and the terrain was steeper.

Harvesting Costs

Harvesting costs generally increased as the level of immature spruce protection increased (Table 8). Costs ranged from \$14.70 to \$14.90/m^3 on the conventional harvesting control blocks, \$13.90 to \$17.40/m^3 on blocks with intermediate levels of immature spruce protection, and \$18.40 to \$25.00/m^3 on blocks with high levels of immature spruce protection.

Harvesting costs were determined by multiplying the scheduled machine hours, determined through the analysis of Servis recorder charts, by the labor and machine rates determined through FERIC's standard costing method (Table 9). These costs are not the actual costs incurred by the company or contractor, and do not include such costs as interest charges, crew and machine transportation, overhead, profit, and risk. New machine prices and salvage values were obtained from equipment dealers in central Alberta. Operating costs (including costs associated with repairs, maintenance, fuel, and lubricants) were either provided by the contractor or based on information supplied by equipment distributors.

Costs for each block varied because of differences in equipment cost and productivity, and level of special harvesting practices implemented to protect immature spruce stems. For example, the costs at the Hinton and Whitecourt Treatment 1 harvesting blocks were \$3.30–\$4.60/m^3 higher than on their respective control blocks because of increased pre-harvest organization, on-site supervision, and bush delimbing. Although blocks harvested with the cut-to-length equipment had the highest costs (\$22.50–\$22.80/m^3), some downstream benefits might be expected in the form of reduced disposal costs for roadside debris and improved sawmill recovery.

Discussion

Results of Project 1480 harvesting studies indicate that once protection prescriptions are established, factors such as equipment selection, on-site supervision, operator cooperation, use of rub-posts, harvesting season, and regulatory cooperation will influence levels of damage to immature spruce stems.

Equipment Selection

It was apparent that the equipment used to fell the merchantable stems directly influenced the amount of immature spruce damaged. For example, when a feller-buncher was used to fell trees, residuals growing between skid-trails incurred minimal damage because the feller-buncher could control the felling direction and bunching location. Harvesters injured significantly more residual stems than feller-bunchers (Table 5) because the harvesters felled the mature stems amongst immature spruce stems. Damage occurred to standing immature spruce stems when falling stems struck them, and when the harvester dragged the felled stem into the head during processing.

The design of felling equipment affected the level of immature spruce protection:

- The swing capability of excavator-type feller-bunchers increased skid-trail width and the potential for trailside damage to residuals.
- The cab was higher on the excavator-type feller-bunchers than on the harvesters or front-end loader feller-bunchers, so the operator of the excavator-type buncher could see over dense clumps of immature spruce.
- The larger cab on the harvesters provided an opportunity for two operators, or an operator

Table 8. Summary of harvesting costs ($/m³)

Block	Cost centers							Additional costs		Total cost
	Pre-harvest organization	Felling or fell/process	Skidding or forwarding	Bush delimbing and topping	Delimbing	On-site supervision	Subtotal	Bulldozer	Other	
No understory protection										
Roadside equipment										
Hinton: Control	0.30	4.90	4.60	–[a]	2.40	0.50	12.70	–	2.00[b]	14.70
Whitecourt: Control	0.40	5.70	3.60	–	3.80	0.70	14.20	0.70	–	14.90
Intermediate level of understory protection										
Roadside equipment										
Drayton Valley: Control	0.30	2.50	8.90	–	2.80	0.10	14.60	2.00	0.30[c]	16.90
Drayton Valley: Treatment 1	0.30	2.00	7.30	–	3.10	0.20	12.90	0.60	0.40[d]	13.90
Drayton Valley: Treatment 2	0.30	3.00	8.80	1.40	3.00	0.30	16.80	0.60	–	17.40
Cut-to-length equipment										
Whitecourt: Treatment 2	0.40	13.20	8.80	–	–	0.40	22.80	–	–	22.80
High level of understory protection										
Roadside equipment										
Hinton: Treatment 1	2.00	5.20	3.20	1.10	2.30	2.30	16.10	0.80	1.50[e]	18.40
Whitecourt: Treatment 1	1.10	7.50	7.10	0.50	3.80	2.80	22.80	0.90	1.30[f]	25.00
Cut-to-length equipment										
Hinton: Treatment 2	0.60	12.50	9.00	–	–	0.20	22.30	–	0.20[g]	22.50

[a] Not used.
[b] Includes manual felling ($0.60/m³) and mechanical slashing ($1.40/m³).
[c] Includes manual felling ($0.30/m³).
[d] Includes manual felling ($0.40/m³).
[e] Includes mechanical slashing ($1.50/m³).
[f] Includes restacking log decks ($1.30/m³).
[g] Includes manual felling ($0.20/m³).

Table 9. Summary of equipment and labor costs

Equipment	Purchase price ($)	Costs ($/scheduled machine hours)		
		Ownership	Operating	Total
Roadside				
Feller-bunchers				
Drayton Valley	300 000	31.80	78.75	110.55
Hinton	372 000	31.99	64.44	96.43
Whitecourt	412 500	35.48	89.43	124.91
Skidders				
Drayton Valley	192 400	16.55	62.17	78.72
Hinton	153 000	13.16	54.98	68.14
Whitecourt	205 000	17.63	62.85	80.48
Delimber	279 000	24.00	71.18	95.18
Slasher	160 000	13.76	41.25	55.01
Hydraulic loader	489 500	35.57	85.68	121.25
Cut-to-length				
Harvesters				
Hinton (Double grip)	400 000	34.40	68.88	103.28
Whitecourt (Single grip)	375 000	32.25	66.88	99.13
Forwarders	240 000	20.64	53.85	74.49
Miscellaneous				
Bulldozer	318 000	27.35	80.46	107.81

Note: Labor: planning and supervision @ $400/person-day; manual felling @ $27/h; manual slashing @ $220/person-day.

and supervisor, to work together to determine the best protection strategies.

- The harvesters and forwarders caused less damage to trailside residuals because they had a narrower stance and because the forwarders carried, rather than dragged, the loads to roadside.

- The profile and configuration of the felling head also contributed to the protection of immature spruce stems; the narrower the head, the less chance for immature stems to be damaged when the mature stems were cut.

Shear and chain saw felling heads would cut an immature spruce stem only if it caught in the head during the cutting cycle; however, the continuously rotating high speed disc saws would inadvertently sever immature spruce stems while the operator was positioning the head. Although the use of an intermittent-rotation disc saw head may be able to reduce inadvertent cutting of immature stems, operators would probably not cut small-diameter stems that had to be cut, but would rather squash them with the head. This may cause damage to adjacent immature spruce stems because of the resulting domino effect.

The method used to attach the felling head to the carrier's boom or stick, and the weight of the head, influenced the productivity of the felling equipment and the number of immature spruce stems left standing after felling. Felling heads that were rigidly attached to a stick, and that had hydraulic devices to control their vertical and rotational movement, could quickly position themselves at the base of stems that had dense branches close to the ground or that were surrounded by immature spruce. Dangle-type felling heads had difficulty reaching into the base of stems with limbs, and sometimes had to cut small-diameter stems that were preventing the head reaching merchantable stems. In addition, the presence of saplings around the harvester head increased the chance of saw bar damage or saw chain jumping because the saplings came in contact with the chain saw bar and running chain.

When using the designated skid-trail pattern over wet ground, selection of the most appropriate log-extraction equipment had to be considered. Because traffic along the designated trails is concentrated, ruts develop in areas of soft, wet soil. Forwarders were better suited than skidders for operating over soft, wet ground because their load was more evenly distributed. Forwarder flotation was further improved when the harvester spread limbs and tops over the trail. However, ruts occurred on several trails at Whitecourt Treatment 2 because even with the mat of limbs and tops spread over the trail surface the ground was too wet and soft to support the loaded forwarder.

Supervision

In all cases where an on-site supervisor was present, production was better than on the control blocks. The supervisor was available to sort out difficulties of scheduling equipment, ensure boundaries were clearly defined, resolve problems arising from skid-trail layout, motivate the crew when necessary, and assist with mechanical repairs.

Also, 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 immature spruce stems were damaged when bunches, placed in a herringbone pattern off the skid-trail, were dragged onto the trail. The least damage occurred when the bunches were accumulated along the skid-trail.

In addition, the presence of an on-site supervisor improved the work habits of operators, especially those with limited interest.

Operators

The immature spruce would not have been protected as well without the cooperation and support of the equipment operators. Operators were faced with devising modified equipment-operating techniques to protect immature spruce stems while minimizing production losses. Operators paid on a piece-rate basis were less willing to accept reduced production levels.

All feller-buncher operators found it difficult to decide which immature spruce stems should be saved. As a result, the feller-buncher operators were instructed to remove all the immature spruce stems that would likely be damaged by skidding. The pre-located and flagged skid-trails assisted the feller-buncher operators because they knew the trails were properly located and that all the stems located on the trail had to be felled. However, the buncher operators did modify the trail locations to avoid sharp corners for skidding.

When the areas between trails were felled, the buncher operators used their own judgement in locating access trails. In dense immature spruce clumps, buncher operators minimized immature spruce damage by entering the clump only if there were merchantable stems of sufficient value to offset the damage. Where densities of immature spruce were low to intermediate, the buncher could take advantage of natural openings within the stand to access merchantable stems.

The skidder operators sometimes modified the trails to increase equipment productivity or to reduce trailside residual damage. Skidder operators were encouraged to make modifications to the trails as early in their skidding activities as possible, to minimize damage to immature spruce stems and to maximize any productivity gains.

Special Practices Incorporated to Reduce Residual Damage

During the harvesting trials, four different operating practices were investigated to determine their effectiveness in reducing damage to immature spruce stems: operating felling and skidding equipment on the same trails; leaving rub-posts and tall stumps alongside the skid trails; delimbing stems before skidding; and re-piling decks after delimbing.

The practice of keeping both felling and skidding equipment to the same trail was effective in protecting immature spruce stems from damage during harvesting. During conventional (control) harvesting, felling and skidding equipment often operated on different trails. Some skid-trails developed through clumps of immature spruce were used to drag only a single bunch or were used as shortcuts to different locations on the block. It was observed during the harvesting trials that the area occupied by skid-trails increased when skid-trails curved sharply or when two or more trails intersected.

The practice of leaving rub-posts beside the skid-trails protected trailside residuals from being damaged by dragged stems at Hinton and Whitecourt Treatment 1 blocks. Even on open areas where aspen clumps were harvested, the rub-posts defined the skid-trail and reduced the area traveled over by harvesting equipment.

Feller-buncher operators at Whitecourt found that when felling merchantable stems surrounded by immature spruce stems, raising the felling head and leaving a tall stump reduced inadvertent cutting of immature spruce stems close to merchantable stems. However, leaving high stumps has a cost because fiber is lost.

If rub-posts and high stumping are to be used to protect immature spruce stems, three operating strategies are suggested to minimize fiber loss. First, avoid felling trailside stems until all other stems have been skidded; second, use decadent or nonmerchantable trees as rub-posts if they are located appropriately; and third, fell the merchantable stems leaving a stump high enough to allow later removal of a minimum log length after skidding is completed.

Delimbing stems before skidding reduced damage to trailside residuals only when the skidded bunches were as wide or wider than the skid trail. Even when limbing the stems before skidding reduced the overall width of the bunch, observations during the studies suggest that for two reasons, this practice was not very effective in reducing damage to trailside immature spruce stems. First, the cut-off branches were swept off the skid-trail, during subsequent skidding, damaging trailside residuals. Second, it was either not possible for the laborer to safely reach all the branches with his saw, or not all the bunches could be limbed. As a result, not all the branches could be removed from all the stems. This meant that some stems or bunches were skidded with protruding branches, and damage occurred to trailside residuals. Delimbing stems before skidding did reduce damage to immature spruce stems when trees were felled off the trail and into immature spruce clumps. In this case, delimbing before skidding reduced the area occupied by the felled stems, and helped reduce skidding damage to immature spruce stems.

Regulatory Cooperation

Policies that influence the type and amount of slash, fiber recovery from a block (such as from leaving rub-posts or sub-merchantable stems), and soil disturbance are critical to effective immature spruce protection. Harvesting practices that protect immature spruce stems can be fully implemented only when the provincial authorities cooperate with harvesting contractors and forest license holders to modify ground rules as required. However, before current standards can be modified, additional research is needed to obtain information on the impact of immature spruce protection on growth and yield, allowable annual cut, growth trends, wildlife habitat, and landscape aesthetics.

Wind Damage to Residual Spruce

The earlier progress report for Project 1480 (Brace Forest Service 1992) concluded that blowdown in released understory spruce is a major concern and that there is a critical need for information on blowdown risk-rating and operating strategies to minimize blowdown damage in released spruce. This conclusion is further confirmed by field observations of operational cutblocks with retained understory in west-central Alberta that provide strong signs of the problem and reinforce the concerns. On the majority of cutblocks without wind protection measures, most of the released spruce is severely damaged by windthrow within the first 3 years after harvesting.

In the treated stands of Project 1480, wind damage was assessed on the 6 m radius growth and yield plots 2, 3, and 5 years after harvesting. The resulting data set has small and uneven sample sizes in different height classes and is insufficient for conclusive analysis. Several observed trends are, however, meaningful. Pooled data from all three areas (Whitecourt, Drayton Valley, and Hinton) show that windthrow damage in the first 2 years after harvesting increased with the height of the spruce (Fig. 5). Spruce trees with heights up to 7 m had damage of less than 5%. Spruce trees taller than 10 m had windthrow losses equal to or greater than 10%. In the same group (trees taller than 10 m), additional losses by windthrow occurred in the third year after harvesting, resulting in a cumulative loss of 15–25% of trees.

Assessment of wind damage 5 years after harvesting showed negligible or no additional increase in windthrow in all height classes (Fig. 5). The lack of significant damage between 3 and 5 years after harvesting is very important. It suggests that spruce stability has gradually improved with time since harvesting. Such an improvement in tree stability results from crown, stem, and root system growth and is a function of increased light and of wind stimulus after release.

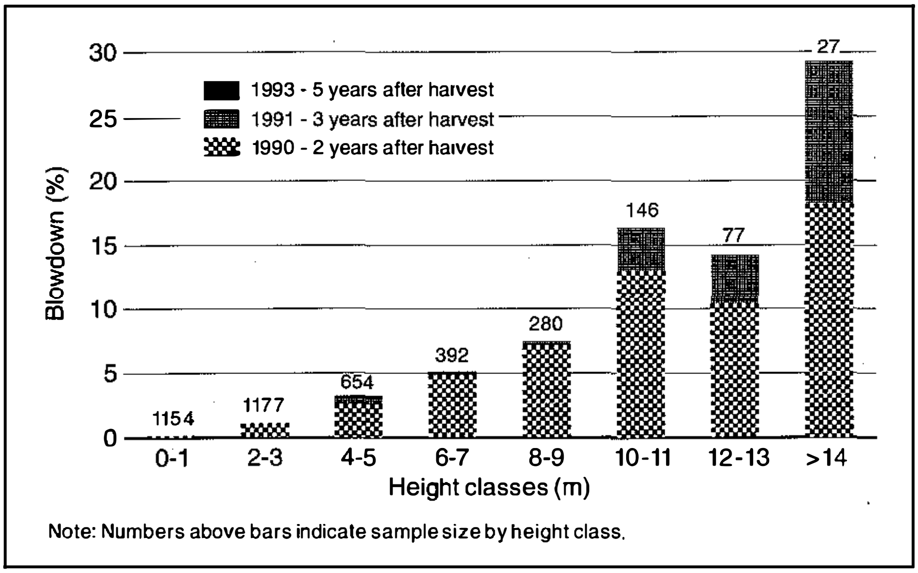

Figure 5. Incidence of blowdown by height class as percent of white spruce understory 2, 3, and 5 years after aspen removal.

Slenderness Coefficient

The slenderness coefficient, expressed as a height/dbh ratio, is closely related to tree stability and thus may provide a simple estimate of wind resistance. In principle, the smaller the coefficient, the greater the wind stability of the tree.

The importance of maintaining well-tapered trees has been intensively studied in Europe and elsewhere. The desirable height/dbh ratios necessary for adequate wind resistance vary according to species and country. In general, in central Europe it is suggested that a ratio of about 80–90 is acceptable for Norway spruce (Navratil 1994).

Slenderness coefficient is often correlated with the type of crown, particularly with the crown length. Longer crowns usually have a lower slenderness coefficient, greater taper, and lower center of gravity. Slenderness coefficient is also influenced by site productivity, age, and stand density. Wider spacing is a prerequisite for the development of well-crowned and well-rooted trees—which are more stable.

Response to Release

How rapidly release growth occurs, and where it occurs, depends on the tree's condition at the time of release (Oliver and Larson 1990). The most critical factors in this process are the crown size and crown condition. Trees beneath an upper canopy (in high shade) may grow vigorously when released if they have large live crowns with many branches and terminal and lateral buds.

No observations were available to describe the crown and tree morphology of white spruce understory before release in the treated stands. Circumstantial evidence suggests that the conditions of high shade under the aspen canopy did not affect the vigor of white spruce and its potential for growth after release. Observations of the released white spruce in the treated stands found no signs of chlorotization or loss of needles. Height and diameter growth increases were evident on most blocks within 2 years after release (Brace Forest Services 1992).

The strongest evidence of spruce growth response on release shows up in the change in its slenderness coefficient. In the order of priorities for allocating the tree's photosynthates, the diameter growth (xylem tissues of stem) receives the lowest priority. Trees under conditions of inadequate light, stress, or poor crown development reduce diameter growth first while maintaining their height growth. As a result, their slenderness coefficient increases.

The opposite trend, a decrease in slenderness coefficients of the released spruce over 5 years since harvesting, occurred in the treated stands in all three areas. Figures 6 and 7 illustrate consistent reductions in the height/dbh ratios in all height classes and density classes. This clearly indicates high photosynthate production and adequate allocation of photosynthates to diameter growth in the retained trees. As well, it provides evidence that, in the treated stands, stand and environmental conditions (i.e., spacing, light, moisture, and nutrient availability) were favorable to white spruce growth.

Of particular significance are the slenderness coefficient reductions in taller trees—those most

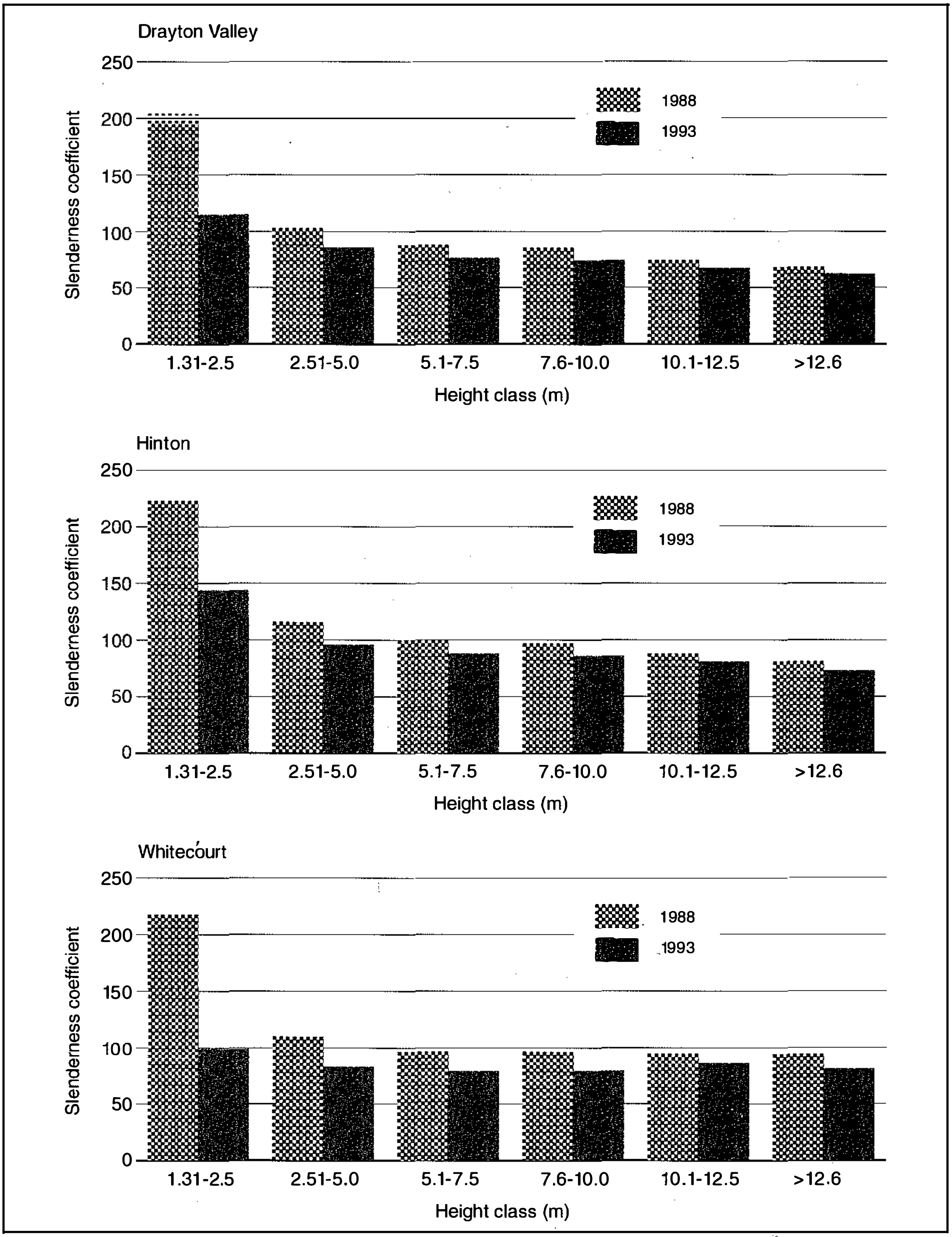

Figure 6. **Changes in the slenderness coefficient of released white spruce by height class in 5 years since harvesting in Drayton Valley, Hinton, and Whitecourt.**

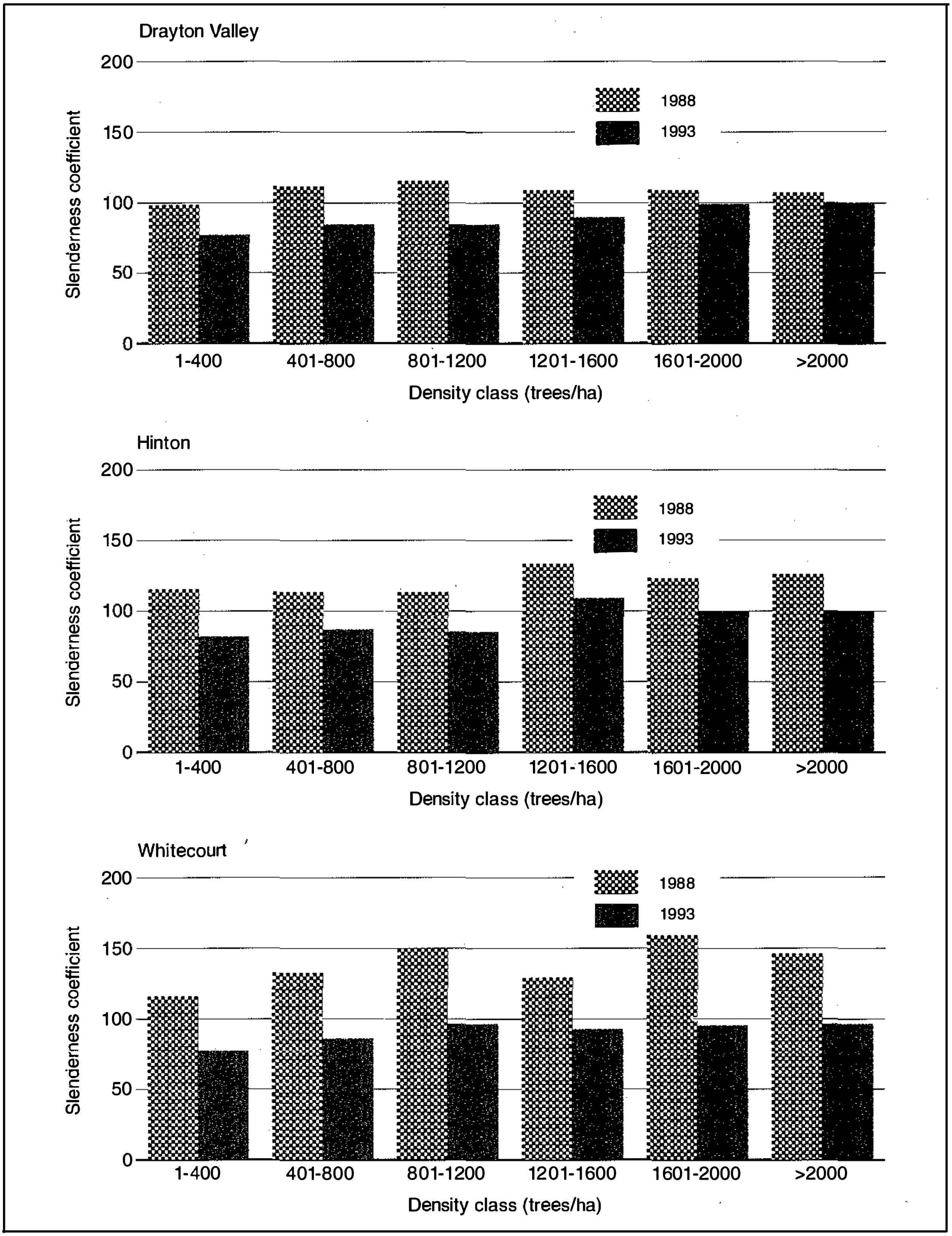

Figure 7. Changes in the slenderness coefficient of released white spruce by density class in 5 years since harvesting in Drayton Valley, Hinton, and Whitecourt.

vulnerable to windthrow. In the three height classes over 7.6 m, the relative changes in the values of height/dbh ranged from 8.8 to 13%, 8.5 to 18%, and 7.9 to 11.3% in the Drayton Valley, Whitecourt, and Hinton areas, respectively (Table 10).

The most important indicator of future wind stability is the current height/dbh value of residual spruce—measured 5 years after harvesting. In several wind risk studies (cited in Navratil 1994) it was found that the probability of windthrow was a function of the time since last thinning or release. In general, there was a rapid decline in windthrow probability in years 1–3; a slight decline in years 4–5; and a very slight or no change 6–10 years since thinning.

Tree stability improvement with time is also directly associated with root system development. There is sufficient evidence in the literature to prove that the current stability of trees develops as a result of stimulus by wind. The tree must be given sufficient stimulus to produce strengthening tissues and propping roots on the lee side of the tree.

Mean height/dbh values of spruce 5 years after release were mostly below 85 in the Whitecourt and Hinton areas and below 75 in the Drayton Valley area. At present we cannot conclude whether or not white spruce with these slenderness coefficients are wind stable, and if so, to what wind speeds. Using a small sample of the windthrown and leaning trees and of the adjacent standing trees in the Whitecourt area, statistically significant differences were calculated for several tree and crown morphology parameters (Table 11).

Damaged trees with a mean height of 9.2 m had a slenderness coefficient of 81 compared to the slenderness coefficient of 75 found for undamaged trees with a height of 6 m. Similar measurements in the Drayton Valley area showed slenderness coefficients of 68 and 62 for damaged and undamaged white spruce, respectively.

This limited comparison shows that, in order to estimate understory stability and develop stand selection criteria and a rating system, a sizable cross section of individual tree measurements and, more importantly, the integration of tree stability characteristics with stand, site, and topography features, will be necessary.

The benefits of release and growth under improved open stand conditions are permanent, provided the trees continue to have adequate growing space. In residual spruce stands, with their variable densities and heights, these conditions are likely to be fulfilled. The observed trend in the treated stands is one of decreased height/dbh values in the 5 years since harvesting, and an absence of significant windthrow in 4–5 years after harvesting. This strongly indicates that white spruce, like other coniferous species, can gain considerable stability in as little as 3–5 years after release. This finding is of paramount importance in confirming the assumptions used in the design of Project 8032 and in developing operating strategies to minimize blowdown damage.

Growth and Yield of Residual Spruce

The silvicultural prescription for control blocks at Drayton Valley, Hinton, and Whitecourt called for post-harvest scarification, planting to spruce, and tending and managing as a conifer land base. Few understory spruce survived the conventional (control) harvest in Hinton and Whitecourt. There, they occurred in isolated clumps, or as individuals in areas of uncut, unmerchantable hardwood and were not useful for assessing residual spruce growth and yield potential in follow-up plot measurements. The Drayton Valley control block had a significant number of released spruce residuals suitable for use in growth and yield assessment.

The prescription for all treated blocks called for the application of the first cut of the two-stage harvesting and tending model described earlier. After the first harvest the released understory spruce is expected to develop along with an aspen crop originating from suckers and seedlings following the first cut, providing a mixed conifer and aspen stand ready for harvest in about 60 years.

Growth data for Project 1480 covering the period 1989–93, and a suggested yield prediction methodology using an example from the project, are presented in the following sections. This analysis is intended only to document treatment response potential of released white spruce. A comprehensive mensurational analysis would require at least a 10-year post-harvest remeasurement.

Data are presented for each area separately, combining plots for all Drayton Valley blocks for Whitecourt Treatments 1 and 2 and for Hinton Treatments 1 and 2. White spruce site index was

Table 10. Changes in slenderness coefficient of released white spruce in 5 years after harvesting by height classes and density classes

		Height class (m)						Density class (trees/ha)											
Area	Year	1.31–2.5	2.51–5.0	5.1–7.5	7.6–10.0	10.1–12.5	>12.6	1–400	N[a]	401–800	N	801–1200	N	1201–1600	N	1601–2000	N	>2000	N
Drayton Valley	1988	204	103	88	85	74	68	98	190	117	101	121	43	110	24	112	12	109	19
	1993	115	86	76	74	67	62	76	190	87	101	88	43	93	24	99	12	100	19
	Change %	−44.0	−16.5	−13.6	−13.0	-9.5	-8.8	−22.5		−25.6		−27.3		−15.4		−11.6		-8.2	
Hinton	1988	223	116	100	97	88	81	118	180	117	147	117	73	138	74	122	47	128	194
	1993	144	96	88	86	81	73	83	179	92	147	91	73	108	74	100	47	110	193
	Change %	−35.4	−17.4	−12.0	−11.3	−7.9	−9.9	−19.7		−21.4		−22.2		−21.7		−18.0		−14.1	
Whitecourt	1988	218	110	96	96	94	94	118	145	139	106	150	47	134	37	157	18	147	44
	1993	99	83	79	79	86	81	78	144	88	106	97	47	92	37	95	18	96	44
	Change %	−66.0	−24.0	−18.0	−18.0	-8.5	−13.8	−33.9		−36.7		−35.3		−31.3		−39.4		−34.7	

[a] N = sample size.

Table 11. **Tree morphology characteristics of wind-damaged and undamaged white spruce understory, Whitecourt Treatment 2**

Characteristics	Leaning or windthrown N[a] = 28	Undamaged N = 21
Height (m)	9.20	6.00 *[b]
Dbh (cm)	11.20	8.20 *
Height/dbh	81.00	75.00 *
Mean crown density		
Lower	1.40	2.10 *
Mid	2.10	1.80 NS[c]
Upper	2.80	2.10 *
Height to crown (m)	2.50	1.60 *
Crown length (m)	6.70	4.04 *

[a] N = sample size.

[b] Statistical significance at $p < 0.05$.

[c] NS = not significant.

comparable between and within these areas, and sample sizes were increased significantly by combining blocks within areas. Crop tree analysis is based on the basal area growth of the three fastest growing trees on each 6 m radius plot, the equivalent of 264 trees/ha.

Figure 8 illustrates harvesting-caused changes in spruce understory density levels in each area. Harvesting reduced spruce density levels, lowering the number of high-density plots in density classes 2 and greater (more than 400 stems/ha) and increasing the number of low-density plots in classes 0 to 1 (0 to 400 stems/ha). Lower-density spruce plots can be expected to have a significant deciduous component at the time of second harvest. Higher density spruce plots can be expected to be primarily conifers by the second harvest. Aspen yield would be expected to increase in proportion to spruce yield decrease. The significance of these changes can only be judged in terms of management objectives. The lower spruce stocking and yield results would be unacceptable for softwood-oriented management, but may be acceptable for mixed-species management once mixedwood yield objectives are set. In terms of non-timber benefits such as wildlife habitat (e.g., hiding cover, thermal cover, and browse for ungulates) or landscape aesthetics, the treatment results have already been judged by project participants as superior to conventional operations (Brace Forest Services 1992).

Diameter and Height Growth

Figures 9 and 10 illustrate diameter and height growth for all residual spruce trees more than 0.5 m in height, and for the three fastest growing crop trees, by 1989 density class.

Although variable between areas, spruce diameter growth response was positive and relatively uniform across the range of densities sampled for all trees more than 0.5 m and for crop trees within each area (Fig. 9). Crop tree response was greater than that for all trees because only the fastest growing trees in the period 1989–93 were chosen as crop tree candidates.

As density increases for all trees, there is a trend toward smaller mean diameters, but not for crop trees. This indicates that even at high densities there is sufficient variability in spruce sizes by age 50 to provide a selection of fast-growing crop tree candidates on all areas. In fact the larger average crop tree size at higher densities in two out of three areas indicates that the selection improves as more candidates are available. It also suggests that by age 50, where understory is highly clumped, a significant number of individual trees are and have been relatively free-growing even in areas of high average density. Tending would not be necessary in order to grow about 264 crop trees/ha under such circumstances. This may not apply where understory stocking has been uniformly very dense on an area, although by age 50, size differentiation tends to occur in spruce even at densities exceeding 2000/ha. Periodic height growth performance is similar to that described for diameter growth (Fig. 10).

Periodic Volume Growth

Figure 11 shows spruce volume increment 1989 to 1993 expressed as periodic annual increment (pai) for all trees and crop trees, respectively, for each area, using number of trees in 1989 taller than 0.5 m as a measure of density.

For all trees taller than 0.5 m, pai increased with density. It was greatest in the Hinton area where it exceeded 5 m^3/ha/yr at higher densities and least in the Whitecourt area, where it reached 3 m^3/ha/yr. This is less than the 30-year pai of 4.83 m^3 reported by Yang (1989) for released white spruce on nine areas in Saskatchewan and Manitoba; but pai may increase marginally beyond the 4- to 5-year post-harvest interval assessed, as released spruce accommodate better to post-harvest stand conditions of

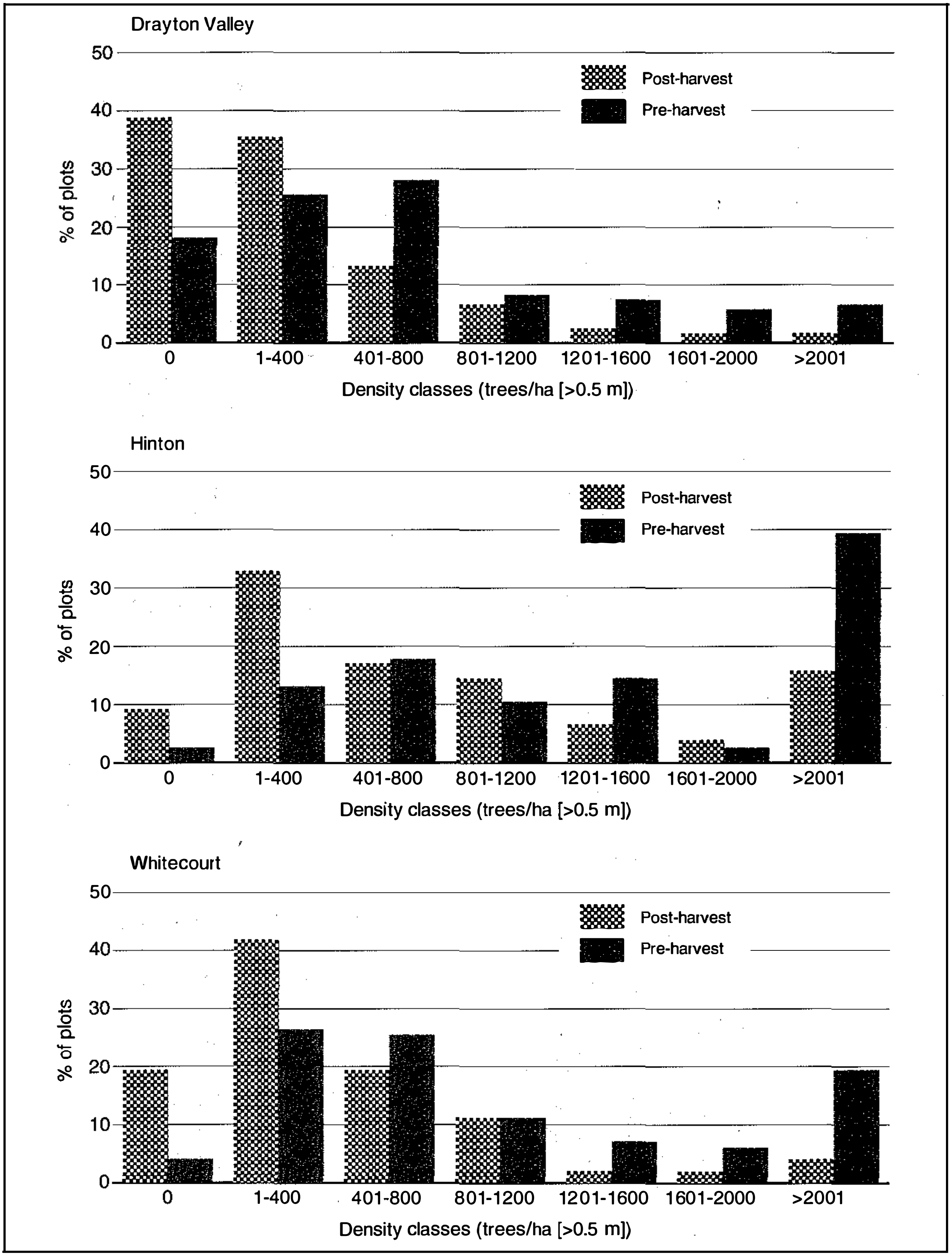

Figure 8. Percent of pre- and post-harvest plots by understory density class.

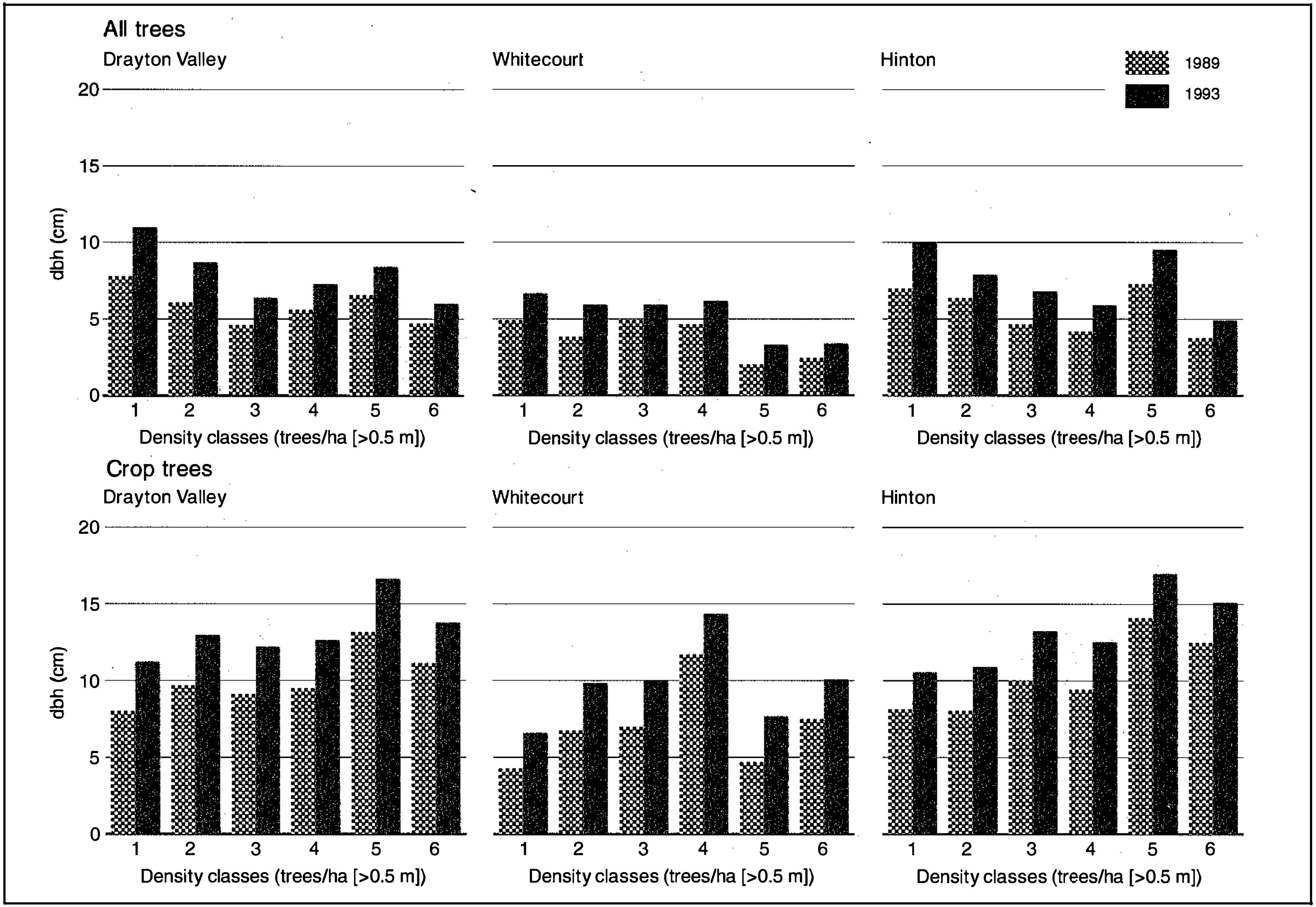

Figure 9. Periodic diameter growth by density class.

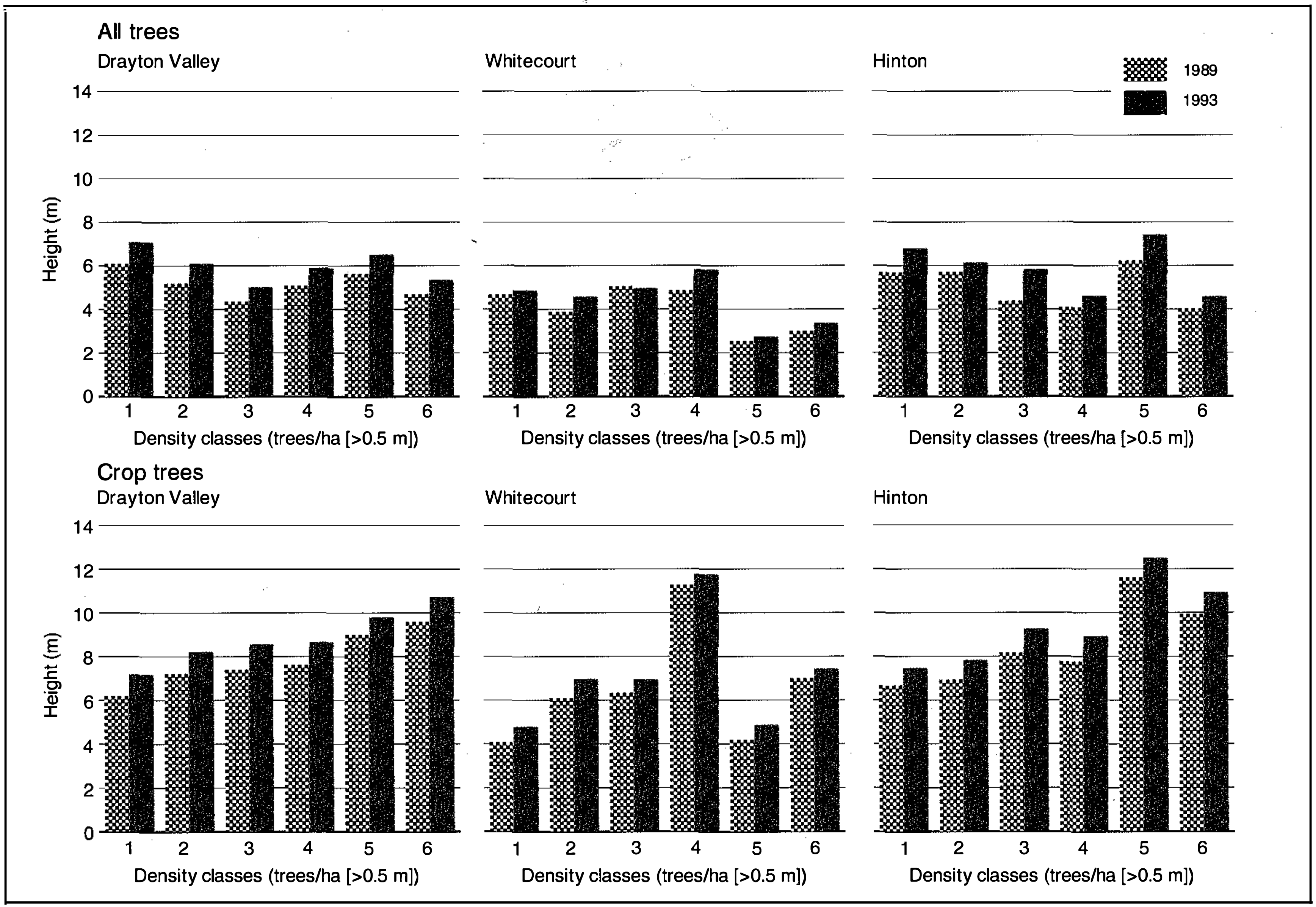

Figure 10. Periodic height growth by density class.

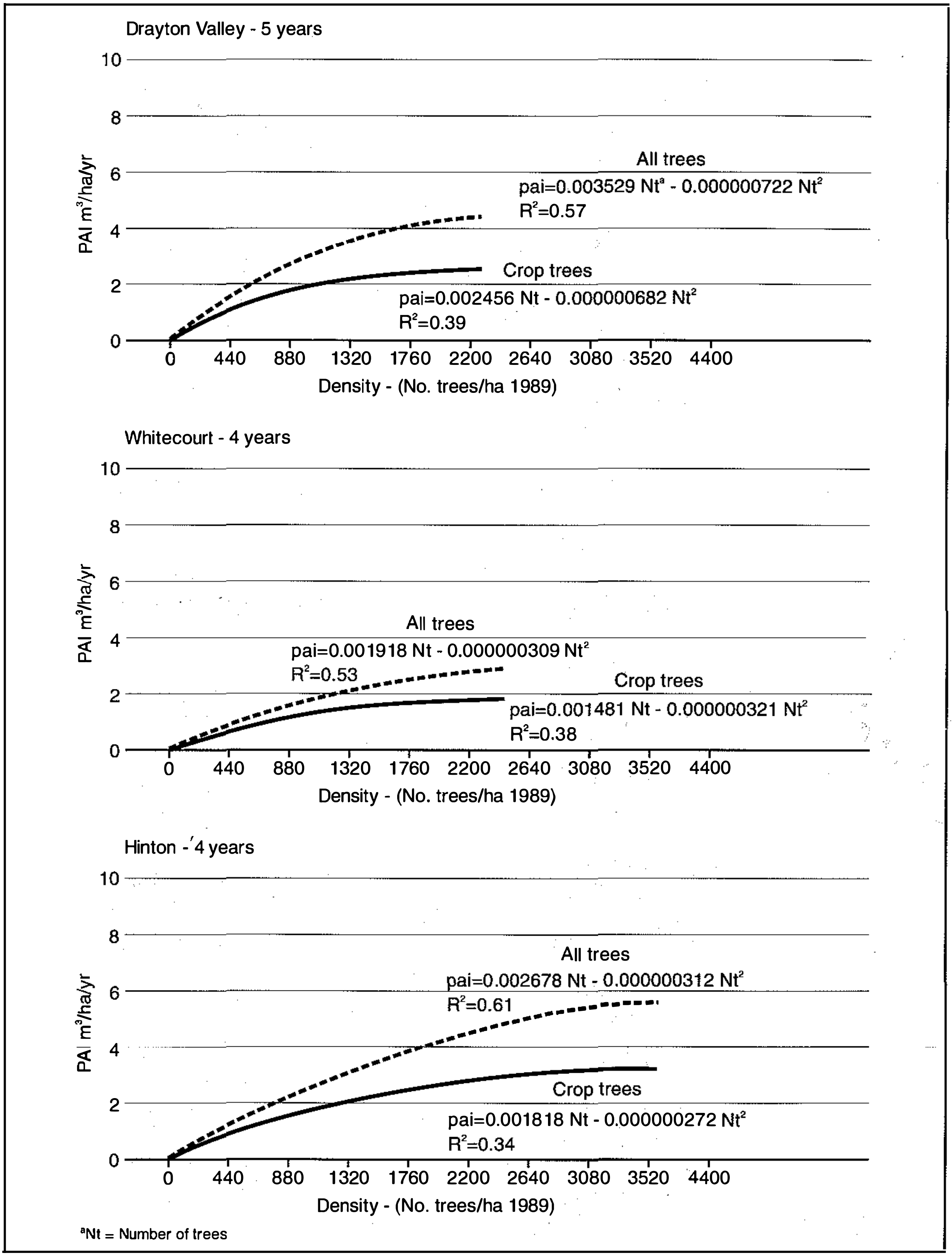

Figure 11. Periodic annual increment (pai) of spruce by density and area.

increased light and nutrients and reduced crown whipping by overstory aspen.

Crop tree pai also increased with density. Growth was lower for stand densities less than 400 trees/ha in 1989 since it was not possible to designate a full 264 crop trees/ha. This resulted in an average of 165 crop trees/ha in Drayton Valley and Whitecourt, and 200 crop trees/ha in Hinton at low stand density. In the time between crop tree selection and final harvest, a period set at 60 years in the model being used, there should be enough large trees in stand densities greater than 440 trees/ha to replace crop trees that die, maintaining at least 264 crop trees/ha, whereas in lower densities this may not be the case, even if there is ingress, because such trees will probably not be merchantable in 60 years.

Yield Projections

Figure 12 shows projected yields for residual white spruce aged 50 years, based on measured yield in 1993, and projected growth for a subsequent 60 years, to age 110, assuming periodic growth between 1989 and 1993 is sustained. Although this growth rate may be conservative in the short term, it may be reasonable over 60 years. Projections were initiated in 1993 because harvest-related mortality and blowdown appeared to stabilize within the 5-year post-harvest period. Each tree was projected separately, then all trees summed for plot and per ha growth and yield. Constraints included a maximum dbh of 50 cm and a maximum height of 25 m at age 110, which seem reasonable for the sites concerned. Mortality was assessed on a volume basis, assuming a compound declining series, at 0.25% for stand densities from 0 to 1320 trees/ha, 0.5% for stand densities 1320 to 1760, and 1% for densities of more than 1760. Mortality rates were derived from Steneker (1967) and Yang (1989), based on permanent sample plot (PSP) data.

The application of yield information by density class can be illustrated by an example from Project 1480 shown in Table 12.

Whitecourt blocks 1 and 2 were stratified into post-harvest density classes for residual white spruce, using number of trees data from the uniformly spaced grid of 6 m radius plots on the area. Aspen regeneration and yield in the 60 years after harvest was assumed to vary with spruce density as shown, and was allocated proportionate to spruce density classes on the block. Spruce yield 60 years after harvest (age 110) was determined for each density class using the appropriate regression from Figure 12, and allocated proportionate to the area of spruce in each density class on the block. Mean block yield for each species and for the mixture was derived as a weighted mean proportionate to block area in each density class. The predicted total block volume yield of 303 m^3/ha for a combination of aspen aged 60 and spruce age 110 years appears to be reasonable when compared to the total block yield of 321 m^3/ha at the time of the first cut, (composed of 238 m^3 of aspen and 83 m^3 of spruce) which represents total volume production of aspen and spruce at the first harvest of the harvesting and tending model, when aspen was aged 85 years (Table 2). The predicted second harvest of 303 m^3/ha has a predominance of spruce (217 m^3/ha) and relatively little aspen (86 m^3/ha) because new aspen regeneration is shaded by the spruce residual, and because of the young age of aspen—60 years—a reversal of species proportion in the yield mix at the first harvest.

The model being tested utilizes aspen while protecting spruce understory in the first harvest and promotes increased spruce residual growth and a new aspen sucker crop for the second harvest. Total yield and conifer AAC implication of this model merit additional study. It could be compared with either removing both species in the first harvest, foregoing the yield potential of the immature spruce, or waiting for natural succession of the conifer crop and forgoing the current aspen crop.

Jarvis et al. (1966), Steneker (1967), and Johnson (1986) reported that the potential for white spruce growth response to release from aspen is greatest in the age range 30 to 70 years. Yang (1989), in an analysis of 30-year spruce release from aspen on nine project areas in Saskatchewan and Manitoba, found that growth response was best in the age range of 15 to 40 years. Good release response has been observed on mixedwood sites for individual spruce more than 70 years old.

The age of residual spruce in Project 1480 varied from 15 to 70 years, with a modal age of about 50 years, an age range not uncommon in mature to overmature mixedwoods with aspen overstories and spruce understories. These stands represent a large proportion of those inventoried H and HS in Alberta as noted earlier. Results of Project 1480 and other studies cited indicate substantial growth potential for spruce release in such stands.

The age of spruce is evidently less crucial as a determinant of post-release growth potential on

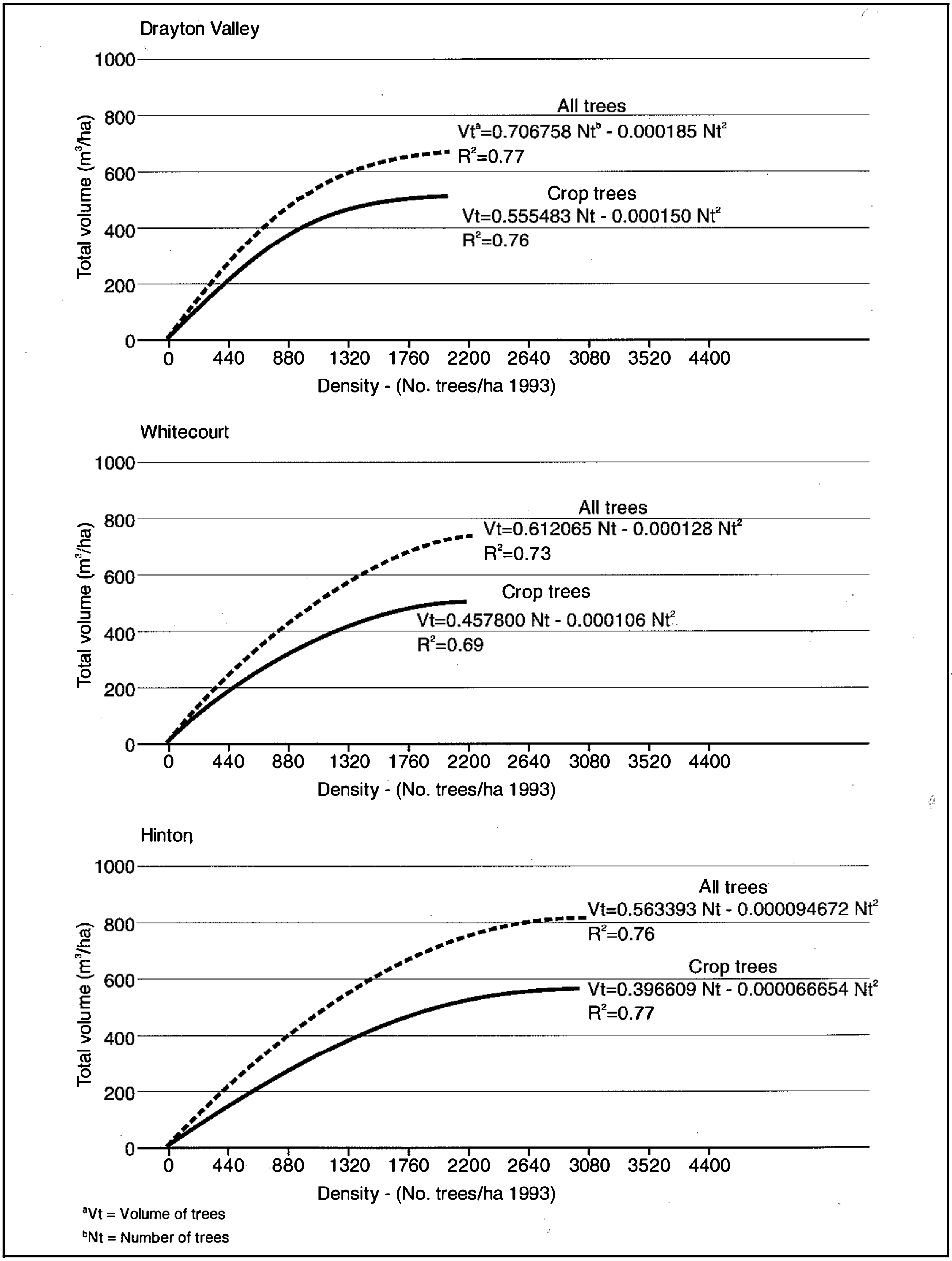

Figure 12. Predicted spruce yield by density and area for age 110 years.

Table 12. White spruce 1993 post-harvest density and future yield, Whitecourt Treatments 1 and 2 (trees/ha)[a]

Variable	Density class							Total
	0	1–200	201–400	401–600	601–800	801–1000	>1000[b]	
No. of plots	19	29	12	10	9	6	13	98
% of plots	19.4	29.6	12.2	10.2	9.2	6.1	13.3	100
Area (ha)	8.09	12.34	5.09	4.25	3.84	2.54	5.55	41.7[c]
Future aspen yield (%)[d]	100	80	40	50	0	0	0	
Species[e]	wS A	wS A	wS A	wS A	wS A	wS A	wS A	
Predicted yield (m^3/ha)	0 172	89 138	172 69	274 34	366 0	447 0	606 0	
Total yield[f] (m^3/ha)	172	227	241	308	366	447	606	
Mean block yield[g] in 2053 (m^3/ha)	white spruce (217) + aspen (86) = 303 m^3/ha							

[a] Number of spruce trees/ha at the end of the 60-year prediction period (age 110) would be reduced by an appropriate mortality factor. For example, application of a compound discount mortality rate of 1% per annum ($100\,[0.99]^{59} = 0.5527$) would result in 700 (0.5527) = 387 trees/ha in the 601–800 trees/ha class by age 110.

[b] Relatively high yields of density classes >1000 trees/ha (see Figure 12) reflect the small plot size (6 m radius) and spruce stocking variability.

[c] Reduced from 43.0 ha (Table 2) due to unproductive landings.

[d] Aspen yield based on an assumed percentage of a total yield of 172 m^3/ha at age 60 (from Johnstone [1977] for Site Index 25.0 m at age 70, trees ≥1.5 m dbhob). Spruce yield from Whitecourt regression equation for all trees ≥0.5 m at age 110 for mid-point of 1993 density range ($V^T = 0.612065\,nt - 0.000128\,nt^2$).

[e] wS = white spruce; A = aspen.

[f] Combined total cubic volume yield of spruce aged 110 and aspen aged 60, by density class. For example, for 1993 density class 1–200, aspen yield = 0.80 (172) = 138 m^3/ha, which is added to predicted spruce yield of 89 m^3/ha from the regression equation noted above, giving a 227 m^3/ha combined value.

[g] Mean total cubic volume yield of the block, weighted by percentage of block area in different density classes for spruce aged 110 and aspen aged 60.

mixedwood sites than are size, and such vigor factors as the physiological condition of crown and root systems, so considerable flexibility exists in the timing of release with respect to spruce age. Steneker (1967) reported that age had little effect on diameter growth for released white spruce over an age range of 10 to 60 years.

There is a need for a mixedwood growth and yield methodology that accommodates the uniqueness of each post-harvest block and can deal with the complexities of variability in number, size, and distribution (clumpiness) characteristic of white spruce understories. Some suggestions for such a methodology include:

1. Use post-harvest photographs at scales of 1:5000 to 1:10 000 to stratify blocks into spruce density classes, either alone or with supplemental ground plots.

2. Follow photo-stratification with ground surveys, that may be modifications of existing regeneration surveys for aspen, combined with stocking surveys and tending assessments for residual spruce.

3. If in-block roads and landings are impacted during harvest so that productivity is impaired, remove them from the productive area when predicting yield, until they are rehabilitated and productive.

4. Use harvesting to simplify subsequent growth and yield prediction by creating relatively pure patches of spruce residuals and open areas for new aspen regeneration. Post-harvest tending of spruce residuals by spacing or thinning can further simplify the system. Cutblock design to mitigate wind damage to released spruce may add necessary complexity.

5. Start models with pure, even-age protocols, assuming age differences in spruce are less significant than size and condition differences. Proceed to more complex methodologies as needed, with input of mortality, growth, age, and competition indexes as appropriate to the post-harvest distribution of residual spruce and of aspen regeneration.

6. Audit blocks at specified intervals to track growth and yield and to fine-tune predictions.

Aspen and Balsam Poplar Regeneration

In stands treated according to the two-stage harvesting model, it is assumed that, after aspen canopy removal, aspen regeneration of acceptable quality would develop in openings and would form the hardwood yield component of the stand at the second harvest (Brace and Bella 1988). The density, stocking, and growth of aspen and balsam poplar after the first cut is of particular interest in yield predictions, as well as in sustaining a mixedwood stand.

Successful aspen regeneration on mixedwood sites is dependent on three prerequisites: availability of regeneration potential (adequate occurrence and density of aspen roots for aspen suckering), increased soil temperature after harvesting, and sufficient light for the growth of aspen suckers after emergence. The physiological condition essential for aspen suckering, i.e., breaking of the apical dominance, is controlled by hormonal balance in roots and is met by cutting aspen trees.

In this project, stand inventories before the first cut harvest indicated a predominance of mature aspen, suggesting a good supply of viable roots for suckering. In general, about 4–5 m^2 basal area of aspen in the parent stand are recommended for adequate regeneration (Perala 1991; Doucet 1989). The mean radius of root systems of single tree aspen in the Alberta foothills has been found to range from 8–14 m, with the overall mean being 10.8 m (Navratil 1993). Based on these estimates, it appears that approximately 50–60 aspen trees/ha with uniform distribution are needed for full aspen regeneration. The volume of aspen harvested in the treated stands suggests that the needed number of aspen trees was present in the parent stand, but their spatial distribution was not known.

The post-harvest surveys also showed a substantial reduction in white spruce understory densities, thus creating space for new deciduous regeneration (Brace Forest Service 1992) and presumably providing adequate insolation, increased soil temperature, and sufficient light for sucker development and growth.

It can be assumed, therefore, that the prerequisites for aspen regeneration were largely satisfied in the first cut. The only deterrents to aspen regeneration would have been disturbances of the ground and of aspen roots caused by harvesting.

Ground disturbance in the treated stands was estimated by interpreting aerial photographs and by regeneration survey plots. Interpretation of photographs determined that about 17% of ground disturbance on main skid-trails and landings was associated with feller-buncher and grapple skidder treatments. This ground disturbance was about twice that of the Scandinavian equipment treatment, which had no landings (Brace Forest Services 1992). Control stands also harvested by feller buncher and grapple skidder accounted for 18% of ground disturbance.

Regeneration survey plots showed that ground disturbance with mineral soil exposure averaged 18.9–22.7% (Table 13), which is comparable to the percentage of recognizable ground disturbance determined from interpreting the aerial photographs.

In all regions where aspen is commercially harvested, heavily disturbed areas of cutblocks are known to regenerate poorly to aspen, and the impact on aspen regeneration and growth is long-lasting (Bates et al. 1990; Navratil 1991, 1993; Shepperd 1993; Kabzems 1993). The main reason for harvesting impact on aspen regeneration is the shallowness of aspen roots. Aspen roots producing suckers are located in the upper 8–10 cm of soil profile and occur frequently on the boundary between organic layers (L, F, H) and mineral soil horizons.

The quality of aspen regeneration may be affected, therefore, by any disturbance of the upper layers of soil profile or by the weight of harvesting equipment, even without recognizable visible surface disturbance (Shepperd 1993). The amount of mineral soil exposed indicates a potentially severe impact on aspen density and stocking. In the duff and traffic classes, which probably represent portions of skid-trails, the conjectural impact on regeneration would be on growth rather than on stocking and density.

Stocking of Aspen

Aspen stocking levels determined by the regeneration surveys for 1 and 4–5 years after harvesting are summarized in Table 14. The overall mean aspen stocking was greater than 80% at both survey times after harvest in all three areas.

Aspen stocking in the Hinton area was uniformly higher, more than 90%, regardless of the ground disturbance class and time after harvesting.

Table 13. Percentage of ground disturbance classes during harvesting (based on regeneration survey plots)

Class[a]	Feller-buncher/grapple skidder: Control	Feller-buncher/grapple skidder: Treatment	Scandinavian equipment
Mineral			
Drayton Valley	20.8	16.0	n/a[b]
Hinton	21.3	31.2	19.4
Whitecourt	22.2	12.3	26.0
Mean for all sites	21.4	18.9	22.7
Undisturbed duff			
Drayton Valley	60.4	54.2	n/a
Hinton	95.5	27.1	30.6
Whitecourt	11.1	38.5	52.2
Duff + traffic			
Drayton Valley	18.8	29.7	n/a
Hinton	53.2	41.7	50.0
Whitecourt	66.7	49.2	21.7

[a] Mineral = mineral soil exposed during harvest; undisturbed duff = no evidence of harvesting-related disturbance; duff + traffic = duff compressed but not displaced by harvesting-related disturbance.

[b] n/a = not applicable.

Table 14. Mean aspen stocking by ground disturbance class (no. of plots)

Area	Years since harvest	Mineral soil			Duff + traffic			Undisturbed			All classes
		Stocked	Not stocked	%	Stocked	Not stocked	%	Stocked	Not stocked	%	% stocked
Drayton Valley	1	12	14	46.1	35	3	92.1	66	18	78.6	81.0
	5	12	14	46.1	34	4	89.4	74	10	88.1[a]	76.3
Hinton	1	32	0	100.0	62	1	98.4	35	1	97.7	98.5
	4	32	0	100.0	63	0	100.0	33	3	91.7[b]	97.7
Whitecourt	1	12	16	42.8	62	4	93.9	48	5	90.6	83.0
	4	22	6	78.6	61	5	92.4	50	3	94.3[c]	90.5

[a] Chi-square test of the differences among the three ground disturbance classes is significant at $p = 0.01$.

[b] Chi-square test of the differences among the three ground disturbance classes is significant at $p = 0.05$ (low validity).

[c] Chi-square test is not significant at $p = 0.05$.

One of the reasons for the consistently higher stocking in the Hinton area, despite the average incidence of mineral soil class, may be related to the depth of mineral soil exposure. In contrast to the two other areas of this project, Drayton Valley and Whitecourt, there was no clearing by bladed equipment in the Hinton treatment blocks.

In the Drayton Valley and Whitecourt areas, the differences between the mineral soil and undisturbed classes were more pronounced. One year after harvest, aspen stocking on mineral soil was about half of that on the undisturbed soil in both areas. Four years after harvesting, stocking in the Whitecourt area increased from 42.8–78.6%. Only in the Drayton Valley area did differences in stocked and non-stocked proportions after harvesting remain statistically significant after 5 years.

In all three areas the differences between duff and traffic, and undisturbed classes were minimal with no practical significance. The stocking levels in these classes were (with the exception of one case) higher than 80%.

Regeneration survey data in this project are not directly comparable to regular provincial surveys because of lower sampling intensity and variable plot size. Furthermore, in all of the above calculations, the term "stocked plot" refers to a plot that contains at least one aspen tree. The Alberta regeneration standards specify that in deciduous establishment surveys done 3–5 years after harvesting, a stocked millihectare plot must contain a minimum of three hardwood trees or less than three in different combinations with conifers.

An approximation of the above provincial survey rule—the minimum three aspen trees per millihectare plot—when applied to our regeneration survey data, showed that only 15, 4, and 12% of our stocked plots from the Drayton Valley, Hinton, and Whitecourt areas, respectively, would be classified as non-stocked by the Alberta regeneration standards for aspen alone. This comparison does not include other hardwood or coniferous species.

Stocking of Balsam Poplar

The overall stocking of balsam poplar 4–5 years after harvesting was very similar in all three areas, averaging 34.8% in Drayton Valley stands, 37.4% in Hinton stands, and 28.6% in Whitecourt stands. These overall 30% stocking levels of balsam poplar seem to be in agreement with the known aspen–balsam poplar associations in boreal forest ecosystems.

In fire-origin ecosystems of the prairie region, aspen stands with 30% or more of balsam poplar are quite common (Winship 1991). In Alberta, balsam poplar represents about 15% of the provincial deciduous inventory. Similarly, based on the total standing volume in western Canada, Peterson and Peterson (1992) summarized the relative proportions of aspen and balsam poplar (as a percentage of the total *Populus* represented) as follows:

Province	Aspen	Balsam poplar
Manitoba	86.1	13.9
Saskatchewan	85.9	14.1
Alberta	83.2	16.8
NE British Columbia	84.6	15.4

In west-central Alberta, in young regeneration established after harvesting stands with scattered clumps of balsam poplar in the parent stand, balsam poplar stocking ranged between 25–80% (Navratil 1993).

The volume content of balsam poplar in the treated stands prior to harvest ranged between 8–19% and averaged 12% (Table 2). The stocking of balsam poplar, as determined in the treated stands after harvesting (Table 15), falls within the generally expected ranges, though it is not clear what the significance is of balsam poplar stocking in the range 30–39% in juvenile stand to future stand development and quality and to growth and yield.

It is important to note that after harvesting, balsam poplar stocking consistently and substantially increased from the 1-year to the 4- to 5-year surveys in all areas and regardless of disturbance class. Such an increase in stocking was not observed for aspen.

The continuous ingress of balsam poplar in the first 4–5 years after harvesting may be explained by its remarkable reproduction and dissemination capabilities in response to disturbance. Balsam poplar is more versatile than aspen in both vegetative (asexual) and seed-origin reproduction. In addition to root suckering, balsam poplar, unlike aspen, also vegetatively propagates and regenerates from the segments of branches and stems broken and buried during logging and from the cut stumps (Zasada and Phipps 1990). Furthermore, the seed of balsam poplar is well-equipped to germinate and produce

Table 15. Mean balsam poplar stocking by ground disturbance class (no. of plots)

Area	Years since harvest	Mineral soil			Duff + traffic			Undisturbed			All classes		
		Stocked	Not stocked	%	Stocked	Not stocked	%	Stocked	Not stocked	%	Stocked	Not stocked	%
Drayton Valley	1	5	21	19.2	8	20	28.6	19	65	22.6	32	106	23.2
	5	9	17	34.6	12	16	42.8	27	57	32.4	48	90	34.8
Hinton	1	9	23	28.1	21	42	33.3	6	30	20.0	36	95	27.5
	4	17	15	53.1	22	41	34.9	10	26	27.8	49	82	37.4
Whitecourt	1	5	23	17.8	15	51	22.7	4	49	7.5	24	123	16.3
	4	8	20	28.6	20	46	30.3	14	39	26.4	42	105	28.6
All areas	1	19	67	22.1	44	113	28.0	29	144	16.8	92	324	22.1
	4–5	34	52	39.1	64	93	34.4	51	122	29.8	149	267	35.8

seedlings on mineral soil. Seedlings of balsam poplar can rapidly colonize soil-disturbed sites and are commonly found on landings of hardwood cutblocks (Navratil 1991).

Density of Aspen and Balsam Poplar

Aspen densities 4–5 years after harvesting varied little between the Drayton Valley and Whitecourt areas, averaging 8613 and 9978 aspen/ha, respectively. In these two areas, lower densities occurred on mineral soil than on duff and traffic, and undisturbed grounds; the difference was probably related to the destruction of shallow aspen roots during construction of landings. Lower aspen density on mineral soil did not occur to such an extent in the Hinton area, where no blading was used and where the overall aspen densities were higher, averaging 21 660 aspen/ha 4 years after harvesting (Table 16, Fig. 13).

In all three areas, the aspen densities 1 year after harvesting were highest in the duff and traffic category. Light disturbance and/or compaction of insulating duff layers may have been beneficial in improving soil warming, resulting in improved suckering. Low soil temperatures and slow warming of soils on hardwood cutblocks are recognized causes of poor suckering on hardwood cutblocks in northern regions (Zasada and Schier 1973; Peterson and Peterson 1992; Navratil 1993).

The average aspen density levels assessed in the treated stands fell below aspen density curves reported in young second-growth stands throughout the commercial zone of aspen (Peterson and Peterson 1992). This result could be anticipated because several attributes of mixedwoods and the retention of white spruce understory created less than optimal conditions for aspen suckering. The literature also suggests that a wide range of initial aspen densities is acceptable for maintaining productive aspen stands (Peterson and Peterson 1992). Stands containing 10 000 aspen/ha 2 years after harvest or 6000 aspen 3 years after harvest are considered minimum acceptable densities (e.g., Doucet 1989). In this context, it is apparent that the aspen regeneration densities found in the treated stands largely satisfied the minimum requirements and were not below the critical thresholds.

Balsam poplar densities were on average within the range of 500–3000 trees/ha (Table 17). These densities compare well with the balsam poplar densities found in the aspen–balsam poplar regeneration surveyed on hardwood cutblocks in west-central Alberta (Navratil 1993; Navratil and Dendwick, unpublished data), where the proportion of balsam poplar and aspen was approximately 1:10. In this project it is of interest to note that the same proportions of balsam poplar and aspen were found on duff and traffic and undisturbed classes in the treated stands; in contrast, on the exposed mineral soil the proportions of balsam poplar and aspen were much higher, ranging from 1:2.5 to 1:5.8, a phenomenon that is likely to be attributable to balsam poplar reproduction versatility. If this trend is confirmed elsewhere, the post-harvest increase in the proportion of balsam poplar to aspen, which had been previously noticed by field foresters, may be related to the degree of ground disturbance.

Height Growth of Aspen and Balsam Poplar

Mean aspen and balsam poplar height by disturbance class in the treated stands is summarized in Tables 18 and 19. Aspen regenerated on mineral soil was smaller than in other disturbance classes. The differences were statistically significant in Drayton Valley and Whitecourt.

Heavily disturbed soils on hardwood and mixedwood cutblocks such as landings are ingressed in the early stage by aspen of seed origin (Navratil 1991). Aspen seedlings have a lower initial growth rate than aspen of sucker origin (Cieszewski and Navratil, unpublished data). The differential proportion and growth of aspen seedlings and suckers possibly accounted for the observed growth differences between aspen growing on mineral soil and other disturbance classes.

In addition, an unknown portion of the mineral soil class probably comprised parts of heavily impacted skid-trails. The lower growth rate of regenerated aspen (measured by height and basal diameter) on skid-trails has been documented by Kabzems (1993), Navratil (1993), and Shepperd (1993).

Although juvenile height growth of aspen and balsam poplar on the same site has been little studied, Huang and Navratil (unpublished data) developed growth functions for juvenile balsam poplar and aspen regenerated on hardwood cutblocks in west-central Alberta. A comparison of these growth functions with the regeneration survey data showed that balsam poplar heights measured in the treated stands were in the expected range, and the mean aspen heights, regardless of ground disturbance class, fell below the predicted

Table 16. Mean aspen density by ground disturbance class

Area	Years since harvest	Mineral soil		Duff + traffic		Undisturbed		All classes	
		No. of trees/ha	N[a]	No. of trees/ha	N	No. of trees/ha	N	No. of trees/ha	N
Drayton Valley	1	6 192	26	16 561	38	15 312	84	13 031	148
	5	4 077	26	9 433	38	9 646	84	8 613	148
Hinton	1	28 000	32	36 603	63	26 333	36	31 679	131
	4	18 281	32	24619	63	19 472	36	21 656	131
Whitecourt	1	7 893	28	16 500	66	12 194	53	17 798	147
	4	5 536	28	12 068	66	9 723	53	9 978	147

[a] N = sample size.

Table 17. Mean balsam poplar density by ground disturbance class

Area	Years since harvest	Mineral soil		Duff + traffic		Undisturbed		All classes	
		No. of trees/ha	N[a]	No. of trees/ha	N	No. of trees/ha	N	No. of trees/ha	N
Drayton Valley	1	1192	26	553	38	438	84	1168	148
	5	1615	26	1088	38	1920	84	1653	148
Hinton	1	1156	32	1476	63	750	36	1198	131
	4	3125	32	1460	63	833	36	1695	131
Whitecourt	1	821	28	1894	66	774	53	1286	147
	4	1571	28	2237	66	1299	53	1772	147

[a] N = sample size.

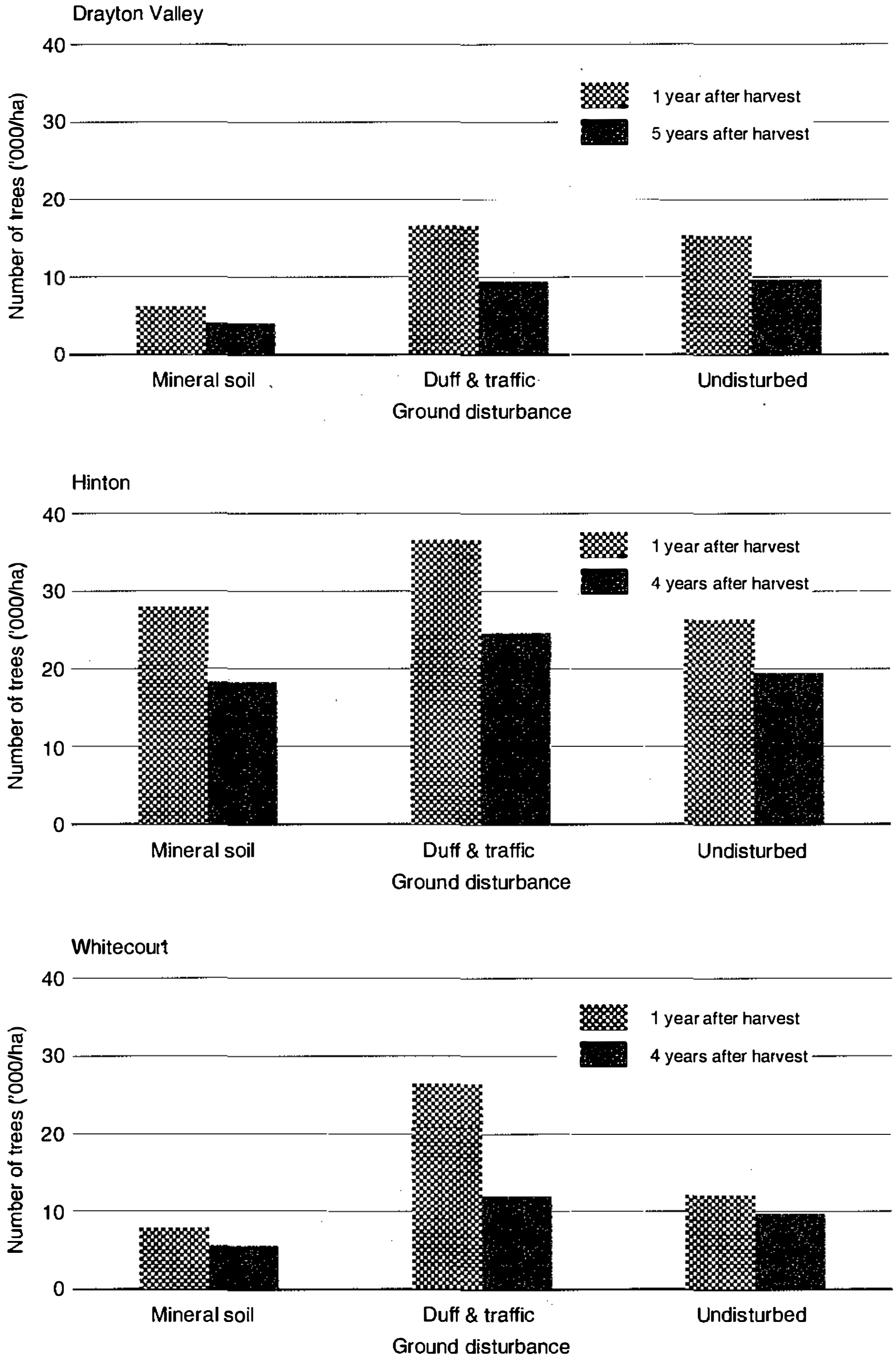

Figure 13. Aspen density by ground disturbance class.

Table 18. Mean aspen height by ground disturbance class

Area	Years since harvest	Mineral soil		Duff + traffic		Undisturbed		All classes	
		Height (m)	N[a]	Height (m)	N	Height (m)	N	Height (m)	N
Drayton Valley	5	1.65a[b]	12	1.76b	34	2.02b	74	1.91	120
Hinton	4	1.32a	32	1.61b	63	1.43a	33	1.49	128
Whitecourt	4	1.09a	22	1.53b	61	1.41b	50	1.41	133

[a] N = sample size.
[b] Means of the ground disturbance classes within the area followed by the same letter do not differ significantly ($p \leq 0.05$) using Kruskal-Wallis Chi-square approximation.

Table 19. Mean balsam poplar height by ground disturbance class

Area	Years since harvest	Mineral soil		Duff + traffic		Undisturbed		All classes	
		Height (m)	N[a]	Height (m)	N	Height (m)	N	Height (m)	N
Drayton Valley	5	1.33	9	1.81	12	1.97	37	1.84	58
Hinton	4	1.07	22	1.02	22	0.78	10	0.99	54
Whitecourt	4	1.23	8	1.42	20	0.77	9	1.22	37

[a] N = sample size.

growth. The lower growth rate of aspen suggests that the white spruce understory created reduced light conditions by shading the aspen suckers, in contrast to open areas of conventional hardwood cutblocks.

Discussion

Aspen regeneration, which was estimated by stocking and density in the first 4–5 years after harvesting in the treated stands, appeared to be at acceptable levels on most areas of the project and comparable with observed aspen regeneration on hardwood cutblocks in the region. About 20% of the Drayton Valley area comprising exposed mineral soil had substandard aspen stocking and density.

Regeneration survey plots were located on a systematic grid, not in open areas, and the plots encompassed areas with variable densities of spruce. Despite the variable density of spruce, the observed aspen regeneration in the first 4–5 years after harvesting was adequate, as conceptualized in the two-stage harvesting model, to stock growing space and open areas in the treated stands.

Future growth and development of aspen in the treated stands is, however, uncertain. Sunlight passes diagonally through a stand during most of the day, especially in high latitudes, and much of the light is intercepted by the crowns of surrounding taller trees, particularly as their density increases (Larson 1982). It is expected that growing space and light available to young aspen within openings will diminish as the surrounding white spruce crowns intercept more light and become larger. Simulations of stand development of white spruce understory using the Tree and Stand Simulator (TASS)[1] model show that the canopy space available for aspen at rotation age could be severely limited, and depends on the density and spatial distribution of the released white spruce. Johnson (1986) calculated that if white spruce understory trees are 2.4 m or taller at the time of release, they cannot be overgrown by aspen and balsam poplar suckers.

PROJECT 8032, BACKGROUND

Planning, Objectives, and Guidelines

The main planning thrust in Project 8032 was directed toward perpetuating healthy boreal mixedwoods by devising silvicultural strategies and designing harvesting plans that test ways to protect and minimize wind damage to immature spruce residuals on moist to wet sites, and encourage vigorous deciduous regeneration following harvesting of the aspen overstory. It is a sequel to Project 1480, which focused mainly on mesic sites where wind damage to residual spruce is a less critical issue. The health and productivity of principal tree species, and their natural regeneration capabilities, were emphasized. Wildlife and watershed concerns were addressed through the relevant Forest Management Agreement (FMA) ground rules and by consultation with specialists in Alberta Land and Forest Services.

Project 8032 was a cooperative study initiated in fall 1992 under the Canada–Alberta PAIF. It included the Canadian Forest Service, Alberta Land and Forest Services, FERIC, and Daishowa-Marubeni Int. Ltd. A working committee of members from the cooperating agencies planned and established the project.

The objectives of Project 8032 were to:

- test the effectiveness of designated silvicultural and harvesting prescriptions for reducing wind damage to immature residual white spruce and encouraging new aspen regeneration;
- assess harvesting productivity and costs for each prescribed treatment;
- assess post-harvest white spruce composition, density, and stock distribution, and subsequent periodic growth in order to develop and refine mixedwood regeneration and stocking standards and growth and yield methodologies; and

[1] Canadian Forest Service and British Columbia Ministry of Forests, Forest Research Branch (unpublished data).

- provide an operational-scale demonstration of alternative harvesting systems in a boreal mixedwood landscape that will facilitate integrated use and contribute to maintaining biodiversity and long-term boreal ecosystems sustainability.

General harvesting prescription guidelines were to:

- use conventional harvesting equipment, including feller-bunchers, grapple skidders, stroke-delimbers, and contractors with previous experience in using the equipment and protecting immature spruce;

- minimize the area occupied by in-block roads and landings to reduce impacts on immature spruce and new aspen regeneration;

- keep feller-bunchers and skidders to a single machine corridor except in controls;

- run machine corridors perpendicular to the main wind direction wherever possible, and keep their width to a minimum on all treatments except the control;

- space machine corridors a minimum of twice the feller-buncher reach apart and keep them to a minimum width consistent with reasonable work efficiency, on all treatments except the controls;

- avoid cutting banks or beds at creek crossings, depositing dirt and silt in the creek, and skidding across creeks;

- avoid cutting banks on ephemeral draws;

- ensure that supervisors and the research team encourage equipment operators to develop operating techniques that minimize damage to immature white spruce stems and roots;

- consider the option to top wide-crowned deciduous trees without complete limbing; this will provide extra spruce protection during skidding and should not pose a fire hazard as could be the case with coniferous tops;

- maintain the option to delay a second pass beyond 5 years in all multi-pass treatments if first-pass areas are still deemed by post-harvest survey to be at high risk to wind damage;

- buffer treatment blocks alongside permanent roads with a 20 m uncut strip to reduce the risk of wind damage;

- apply the current FMA Operating Ground Rules with respect to minimizing site impacts during harvesting operations; and

- be aware that current harvesting prescriptions are constrained by available technology; new harvesting technology may change future harvesting prescriptions.

Prescription guidelines specific to wildlife were to:

- achieve a maximum 200 m line of sight from the road for cutblocks along permanent roads by using 20 m buffers and/or residual immature conifers within the treatment block;

- leave a minimum buffer of 30 m along active beaver dams where more than one-third of the dam is affected by harvesting;

- retain minor vegetation on intermittent creek banks;

- roll back debris at strategically located "choke" points on in-block roads to restrict access;

- take care to minimize the loss of dead standing trees during harvest and maintain living trees in accordance with specific treatment prescriptions; and

- maintain harvesting debris within the blocks by leaving merchantable pieces that are inaccessible from skid-trails and retaining small debris piles at decking areas.

Additional measures to increase protection of immature white spruce include:

- change harvest prescriptions if additional information collected during pre-harvest surveys for initial layout indicates a better harvest prescription or layout;

- change sequence depending on weather, ground conditions, and availability of equipment at the time of harvesting; sequence blocks for summer and winter harvest after completion of ecosite surveys;

- move block boundaries inside the current boundaries if there are minimal merchantable stems;

- be flexible in enforcing merchantability standards: merchantable stems that are not accessible to the felling head without damaging or cutting immature spruce will be left, only spruce with diameters larger than 30 cm will be harvested, and high stumps along skid-trails will be left at the approach to decking areas as necessary to protect spruce from skidding damage; in addition, only merchantable pieces on the machine corridors will be recovered and pieces or stems will not be recovered between corridors if this removal would damage immature spruce;

- only recover windthrown timber during the period of active operations after consultation with the Project Coordinator or the Canadian Forest Service;

- fell trees into the standing timber adjacent to the boundary to avoid cutting a perimeter boundary in specified treatments; and

- relax the slash-free zone requirement between machine corridors and standing timber within the cutblocks in specified treatments.

Detailed silvicultural and harvesting prescriptions for each treatment are reported later.

Pre-Harvest Surveys and Study Methodology

Eleven treatment blocks were selected near Manning, in northwestern Alberta, using an upgraded inventory derived from color infrared photographs at 1:10 000 typed to Alberta Vegetation Inventory (AVI) standards, which enhanced understory (immature) spruce information. Four additional control blocks were selected to track stand development without treatment. Pre-harvest blocks statistics are shown in Table 20 and block locations are shown on the map in Figure 14.

The pre-harvest species composition, density, distribution, and volumes for principal species on the project area are characteristic of regional mixedwoods at overstory aged 80 to 100 years. Aspen age in treatment blocks ranged from 86 to 91 years. Most of the treatment blocks qualify as deciduous land base. Three are within the current definition of conifer land base of 50 m^3/ha, the largest being 76 m^3/ha merchantable conifer. White spruce densities averaged 774/ha, ranging from 323 to 1550. Spruce age averaged 60 years and dbh and total height averaged 11.6 cm and 10.6 m respectively. All harvested blocks ultimately would have become conifer land base through natural succession over the next 30 to 40 years if left unharvested.

Basic Survey Grid

A treatment survey was designed to sample each block at an intensity averaging 2.8%, with transects located as shown in Appendix 1. Transects are 5 m wide; length varies with block or strip width. Total pre-harvest transect length was 20.45 km. Transects are located perpendicular to harvesting machine corridors and sample the moisture gradient across each treatment block. Placement was constrained by harvesting pattern, to minimize loss of transects due to placement of landings and in-block roads.

Pre-Harvest Surveys

Ecosites were mapped from 1:10 000 color infrared photography in 1993. The predominant ecosite is GL1 (glaciolacustrine, moderately well drained) on mid-to-upper slopes, grading to GL2 (glaciolacustrine, imperfectly drained) and OGL2 (organic over glaciolacustrine, very poorly drained) on lower slopes. These ecosites lie within the Lower Boreal Cordilleran Ecoregion (now the Foothills Natural Region Lower Foothills Natural Subregion), characterized by Gray Luvisol soils, and Ecodistrict 9CL, characterized by rolling morainal uplands. The climate and ecological conditions are defined by W.L. Strong Ecological Land Surveys Ltd. (1992).

Pre-harvest assessments (PHAs) were conducted in May and June 1993, using the above ecosite survey information and a 1991 AVI map at 1:5000. PHA forms provided by Alberta Land and Forest Services were used for soils and vegetation assessments, with special consideration for soil texture, structure, and moisture conditions. Blocks were given summer and winter harvesting status based on the survey. The ecosystem associations that most closely agree with PHA assessments are defined by Geographic Dynamics Corp. (1993) as MBMD C10 and MBMD C11, both deciduous-dominated systems with aspen over buffalo-berry (*Shepherdia canadensis* [L.] Nutt.) and aspen over low bush cranberry (*Viburnum edule* [Michx.] Raf.) and bunchberry (*Cornus canadensis* L.). Archibald (1986)

Table 20. Summary of pre-harvest statistics for stands inventoried in 1993, Project 8032

Block	Treatment	Location	Aspen age (yr)[a]	Block size (ha)	Transect sample		Total volume (m^3/ha)[b]				Merch.[c] white spruce		No. trees/ha > 0.5 m	
					ha	%	Aspen	Poplar	White spruce	Total	Volume (m^3/ha)	Dbh (cm)	White spruce	Aspen and poplar
F-1-1	One-pass control/modified uniform shelterwood	2-94-1-W6	91	59	1.55	2.63	253	48	48	360	32	10.97	533	721
F-1-2	One-pass control	2-94-1-W6	89	61	1.80	2.95	230	23	43	318	32	13.79	323	864
F-2	One-pass modified uniform shelterwood	34-93-1-W6	88	28	0.92	3.29	268	25	69	362	37	10.49	975	783
F-3	Two-pass modified uniform shelterwood	3-94-1-W6	88	35	0.84	2.40	271	18	82	371	42	8.94	1550	917
F-4	Two-pass shelterwood/50 m strip	4-94-1-W6	89	36	1.14	3.17	234	43	88	367	57	11.10	981	1039
F-5-1	Three-pass shelterwood/50 m strip	4-94-1-W6	89	40	0.99	2.48	168	85	86	339	56	10.40	976	836
F-5-2	Three-pass shelterwood/100 m strip	3-94-1-W6	88	32	1.10	3.44	218	18	120	358	76	9.94	1510	722
F-6-1	Two-pass alternate 50 m strip	2-94-1-W6	86	25	1.00	4.00	239	46	62	378	45	13.85	460	653
F-6-2	Two-pass alternate 100 m strip	3-94-1-W6	87	38	1.22	3.31	236	101	69	406	45	12.40	650	772
F-6-3	Two-pass alternate 150 m strip	2-94-1-W6	88	67	1.74	2.60	232	55	56	362	31	9.85	840	786
F-7	Four-pass progressive 50 m strip	20-94-1-W6	90	61	1.66	2.72	269	21	43	336	29	14.28	337	999
	Control 1	3-94-1-W6	89	12	0.19	1.58	227	85	59	371	17	8.37	1521	713
	Control 2	3-94-1-W6	87	10	0.29	2.90	232	37	35	331	18	11.61	427	706
	Control 3	3-94-1-W6	87	16	0.38	2.38	267	26	69	366	50	13.58	520	703
	Control 4	4-94-1-W6	89	8	0.22	2.75	189	107	27	332	66	10.77	1216	799
Totals and weighted means			88	528	15.04	2.85	238	45	64	356	41	11.55	774	825

[a] Total age of aspen from stem analysis of 10 trees per block.

[b] Includes all species, derived using local height–diameter curves and volume equations for Volume Region 6. Minor amounts of lodgepole pine, balsam fir, and white birch included in total (Alberta Energy and Natural Resources 1985).

[c] Merchantable utilization standard 15/10 applied (Alberta Energy and Natural Resources 1985).

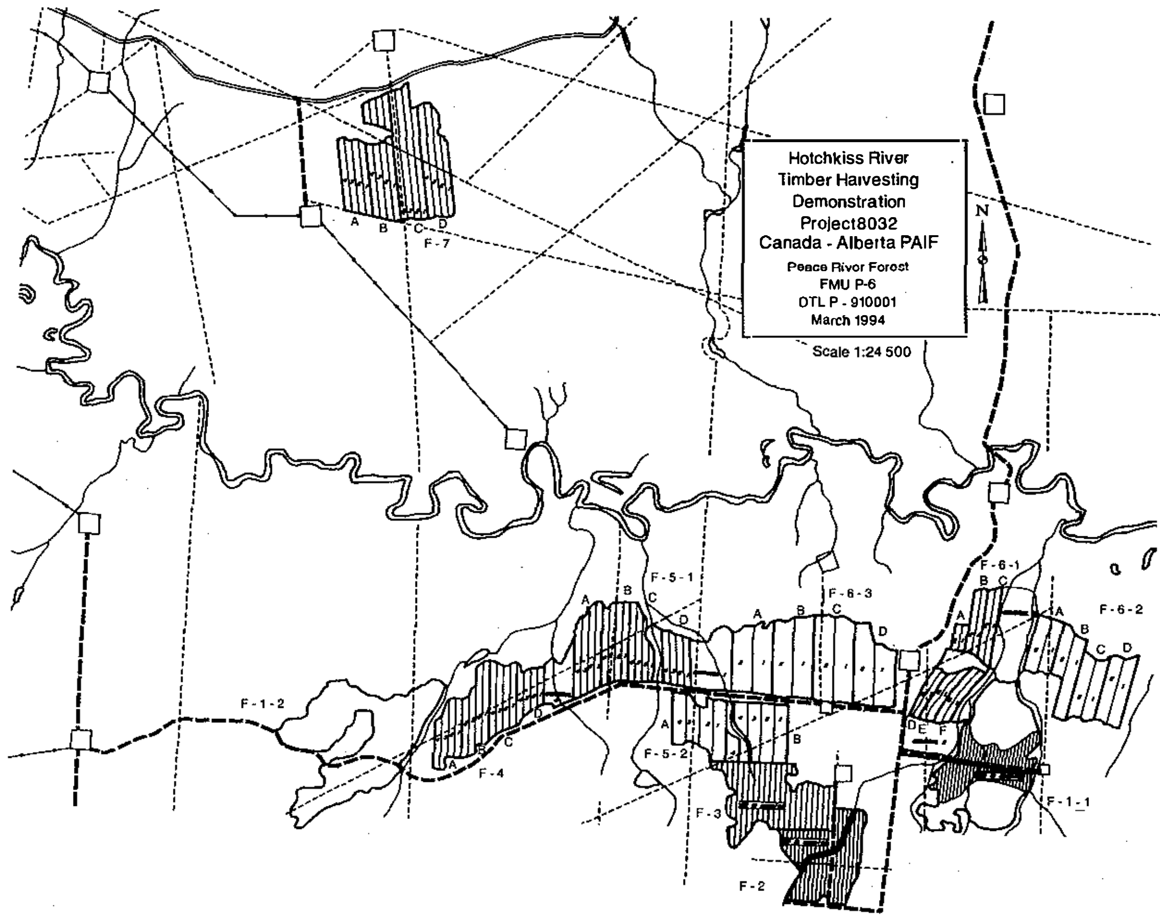

Figure 14. Map of Project 8032 area.

defined two similar associations within the aspen–white spruce variant of the Boreal Mixedwood Lower Subzone in northwestern Alberta.

Pre-harvest transect measurements for the first harvest pass area were completed in 1993, using protocols in Appendix II. Such measurements will be conducted before each subsequent harvest pass to complete silvicultural treatment prescriptions in 1999, 2004, and 2009, on a selection of transect sample plots (TSPs) covering a range of sites and of spruce density and stocking.

A pre-harvest survey of selected spruce trees and surrounding stand conditions was conducted in 1993. Tree characteristics affecting wind stability (height, slenderness, crown shape, size, and density) were measured along with adjacent stand basal area and crown closure, and detailed age, height, and branch growth detail required for modeling wind stability characteristics of individual spruce trees. Protocols are given in Appendix III.

A wind monitoring tower was set up on the project area in September 1993, supplemented by a tower at the Manning airport, to record and analyze regional and local wind events for use in interpreting general blowdown incidence by treatment. Additional within-treatment wind behavior research by the University of Alberta will enhance analysis and interpretation of treatment results, and assist in generalizing project results to other areas. This research is being funded by the Alberta Forest Development Research Trust Fund and the Manning Diversified Forest Products Trust Fund.

Design of Silvicultural Systems to Minimize Wind Damage

Wind damage in forest stands tends to increase as natural stand conditions change under silvicultural and management practices. In anticipation of high wind damage in the two-stage harvesting system and in other silvicultural systems applicable in boreal mixedwoods forests, a study was initiated at the Northern Forestry Centre with the objective of reviewing the wind risk problem and providing recommendations on minimizing wind-induced losses.

In the first stage of the study, an analysis of wind statistics determined the likelihood of extreme wind gusts in Alberta (Flesch and Wilson 1993). This report by Flesch and Wilson (1993) gives the maxima, return periods, and directions of gusts for specific locations in Alberta. The information is essential for highlighting the areas requiring special consideration for wind protection and for planning silvicultural and harvesting systems.

In the second stage, a review of the pertinent literature and experiences in wind-risk management in other regions and countries provided a conceptual background for wind protection measures that could be applied in the two-stage harvesting system. The review report (Navratil 1994) summarizes the principles of wind behavior and tree and stand stability and was used to design an array of silvicultural systems with incremental wind protection levels. The selected silvicultural and harvesting options were subsequently implemented in Project 8032.

The approaches and measures for reducing wind damage in released white spruce understory fall into four categories:

1. Assessing windiness in the general area and in specific stands.
2. Identifying wind stability characteristics of white spruce understory.
3. Reducing wind damage in white spruce after the removal of the aspen canopy, primarily using protection from adjacent stands and from created windbreaks.
4. Improving windfirmness of white spruce understory by shelterwood silviculture and/or by spacing before the final harvesting and canopy removal.

Windiness in the Peace River Region

The probable occurrence of high-speed winds, and their directional characteristics, must be known before wind-risk management and mitigating measures can be implemented. The analysis of wind statistics in Alberta by Flesch and Wilson (1993) focused on determining the return periods for maximum gusts—those that are most damaging and cause windthrow.

The directional analysis of annual maximum winds shows the predominance of extreme winds from the northwest and west in Alberta (Fig. 15). At Peace River (airport station) 79% of annual wind gusts are from a westerly direction. The seasonal differences were also examined, since variable soil moisture and frozen ground affect soil cohesion and anchoring of trees. The frequency of west-oriented extreme wind gusts at Peace River changed little with season, being 72% in winter (November–March), 66% in spring (April–June), and 79% in summer and fall (July–October). At Peace River, higher wind gusts occur in the winter than in other seasons.

Based on these generalizations, harvesting and silvicultural systems were designed on the assumption of prevailing westerly direction maximum wind gusts. All longitudinal axes of cutblocks and strips were oriented north and south, perpendicular to prevailing winds. The harvest sequence of multipass systems was scheduled to progress from east to west.

Tree stability after release improves with time because of wind stimulus and development of a fuller lower crown. Knowing how long the stand will be without damaging winds, or knowing the typical period between certain wind speed events (return period), would help sequence subsequent harvest passes. Damaging winds should not occur until released trees have improved their stability and are able to withstand the level of wind anticipated.

The return periods for winds of certain speeds in the Peace River and High Level regions are shown in Table 21. The data indicate that, for example, wind speeds of 70 km/hr can be expected every year (as the return period for 70 km/hr wind is one year). Similarly, wind speeds of 90 km/hr can be expected every 4–5 years. The second part of Table

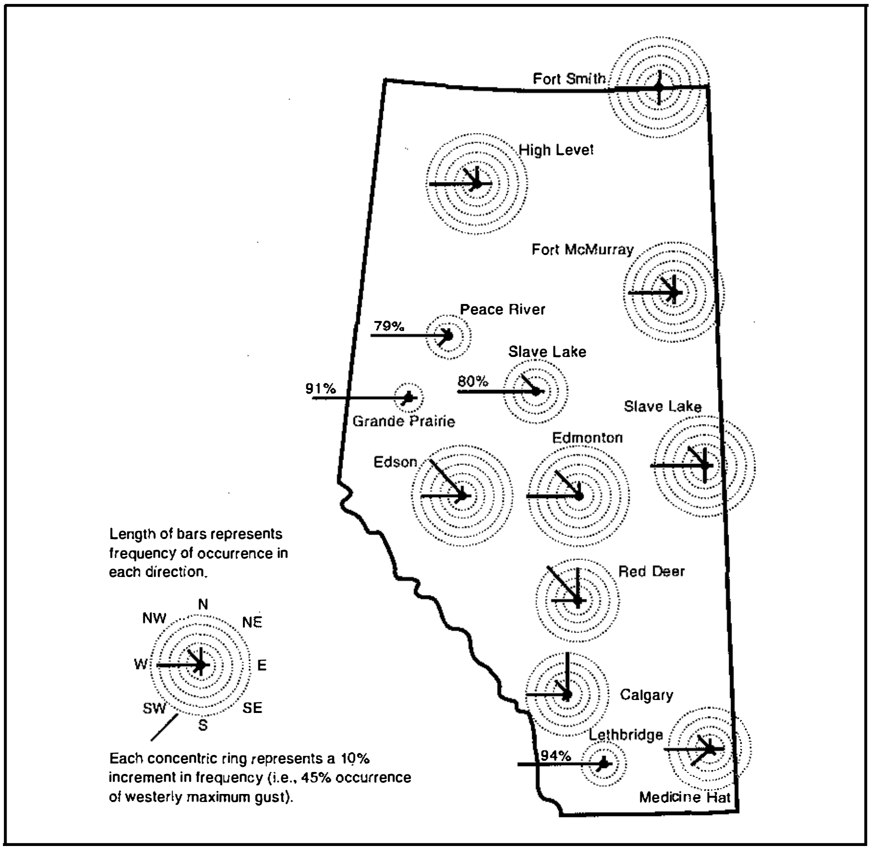

Figure 15. Directional frequencies (wind rose) for annual extreme wind gusts.

Table 21. Return periods of maximum wind speeds in Peace River (airport station)

	Return period (yr)			
Wind speed (km/h)	Annual	Winter	Spring	Summer
50	1.0	1.0	1.0	1.0
70	1.0	1.4	1.4	1.4
90	4.2	9.0	11.6	9.5
110	100.5	86.0	163.7	104.8
130	999.0	857.6	999.0	999.0
	Wind speed (km/h)			
Return period (yr)	Annual (SD)[a]	Winter (SD)	Spring (SD)	Summer (SD)
2	84.4 (1.3)	74.6 (1.9)	74.8 (1.6)	75.1 (1.8)
5	91.2 (2.2)	84.4 (3.2)	83.2 (2.7)	84.3 (3.0)
10	95.8 (3.0)	90.9 (4.3)	88.8 (3.7)	90.5 (4.1)
21	100.1 (3.8)	97.2 (5.5)	94.2 (4.7)	96.3 (5.1)
50	105.8 (4.8)	105.3 (7.0)	101.1 (6.0)	103.9 (6.5)

Source: Flesch and Wilson (1993).

[a] SD = standard deviation.

21 shows that, on average, wind speeds of 84 km/hr can be expected every 2 years, and every 5 years wind speeds of 91 km/hr are likely to occur.

Since at least 5 years are generally needed for tree stability improvement in released conifers (Navratil 1994), it is obvious that, in the Peace River region, high-intensity wind protection measures must be included to counter the frequent return of periods of relatively high wind speeds.

Between October 1993 and March 1994, short-term wind measurements in the area of the project recorded wind gusts of more than 80 km/hr that caused considerable windthrow incidence in the blocks with limited or no protection.

Height, Slenderness Coefficient, and Tree Stability of White Spruce

Tall and slender trees are more susceptible to wind damage. Thus, a cursory estimate of the understory stability after canopy removal could reasonably be based on the measurements of tree characteristics before harvesting.

The assessment of tree morphology of white spruce understory in the project stands was designed to test this premise, as well as elucidate the relationships between white spruce tree morphology and stand characteristics (Appendix III).

To date, only a partial analysis of 25 white spruce trees per stand has been completed. Mean height of understory spruce was very much the same for all stands, ranging from 9.26 to 11.18 m (Fig. 16).

More important than height alone is the ratio of height/dbh (termed slenderness coefficient). Slenderness coefficient is a useful index of stand and tree susceptibility to wind and is briefly described previously and reviewed in detail in Navratil (1994).

The values of height/dbh determined in the spruce understory were consistently higher than 100 in all project stands. Though tree stability indexes cannot be extrapolated from region to region or species to species and must be interpreted carefully for local conditions, the observed values of higher than 100 do indicate a high risk of instability. This is particularly true for this spruce understory, which had a uniform height of about 10 m with only a few smaller and younger trees (that, with their higher height/dbh ratio, tend to inflate the height/dbh value).

The slenderness coefficient values are correlated with crown morphology (its shape and size), which in turn is controlled by light conditions in the understory strata. The crown morphology of shade-tolerant spruce may be affected more by side shade from neighboring spruce trees than by high shade conditions (shade cast by the upper canopy). Highly dense clumps of white spruce understory tend to have high height/dbh ratios because they may grow just as in pure conifer stands—tall but with restricted diameter.

A simple linear regression proved that two stand characteristics—number of spruce understory trees per hectare taller than 0.5 m and spruce volume per hectare—were important in determining slenderness coefficient. The number of spruce trees explained 73% of the variation in mean slenderness coefficient and the volume of spruce explained 68% of the variation in mean slenderness coefficient (Figs. 17, 18). The results of this limited analysis confirm the postulated relationships: higher spruce density and volume in the stand, and greater side shade, lead to higher slenderness coefficients.

Only broad correlations can be expected between height/dbh and the incidence of windthrow because risk of wind damage depends not only on the slenderness of the tree population but also on the dynamic properties of the stand, on wind behavior, and on other conditions. However, the consistently high values of height/dbh of white spruce understory in Project 8032 stands raise concerns about low stability of spruce. These concerns are further enhanced because of average tree height (about 10 m). The incidence of windthrow damage is known to increase with height, as wind speed increases exponentially with distance from the ground. In Project 1480, the cumulative damage in height classes over 10 m was at least twice as high as windthrow damage in trees less than 10 m tall.

In conclusion, the combination of all three factors—high slenderness coefficient, mean height of 10 m, and windiness of the region (short return period of high-speed winds)—coupled with potential intermittent saturated soil conditions, suggest a high risk rating and danger of extensive windthrow in retained spruce in unprotected cutblocks. Wind protection measures should be intensive and given a high priority in the design and selection of suitable silvicultural systems for Project 8032 and similar stands in the region.

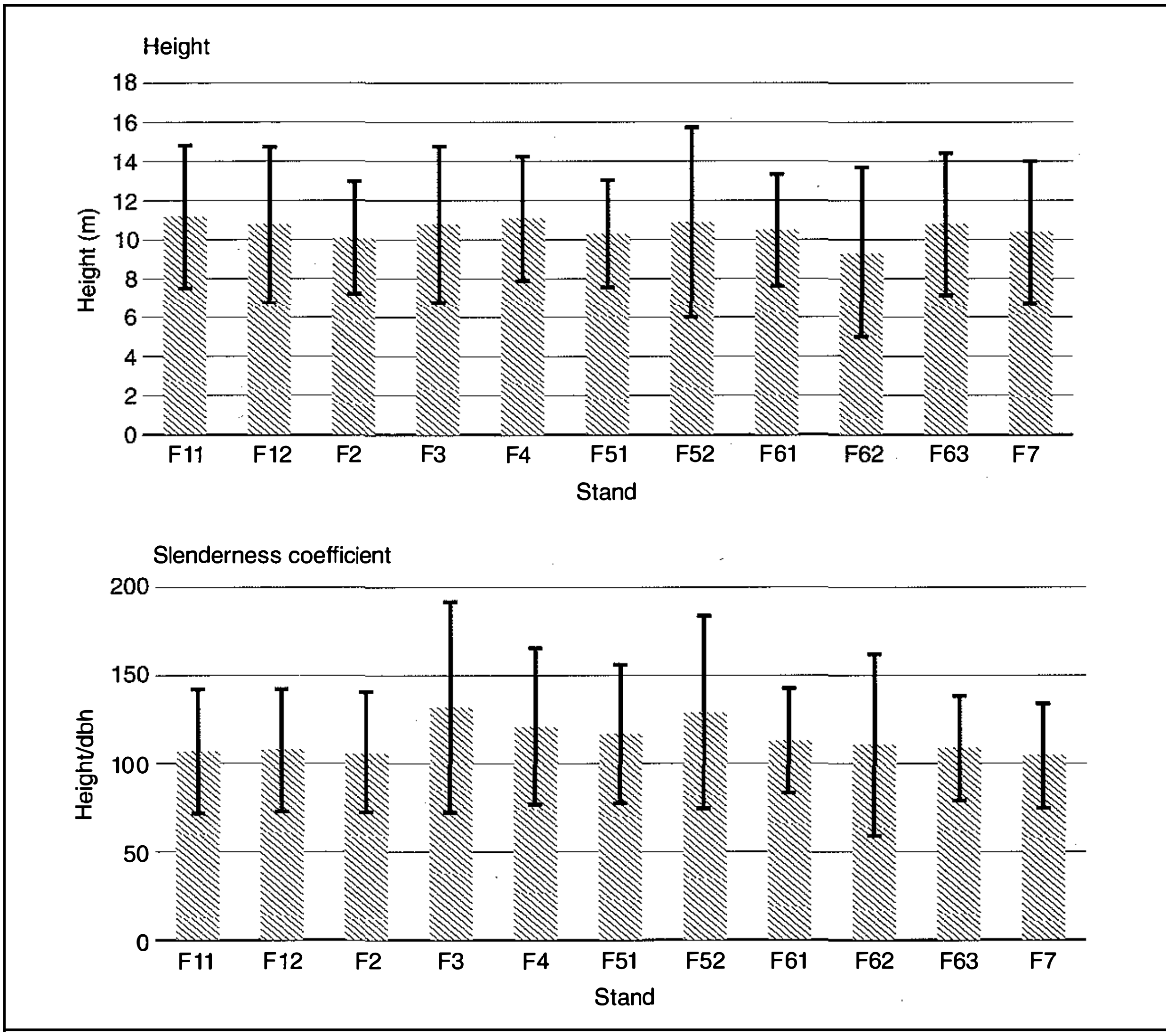

Figure 16. Height and slenderness coefficient of 25 white spruce understory trees sampled in each stand, with standard deviation represented by vertical lines.

Design of Silvicultural and Harvesting Systems for Project 8032

The major assumptions used in the design of silvicultural systems for minimizing wind damage were that:

- maximum wind speed will not be greater than 50–70% of the open field wind speed up to a distance of two stand heights from the upwind edge of cutblock or strip;
- removal of about 50% of the aspen canopy in shelterwood systems will adequately increase light and provide enough wind stimulus to improve tree morphology and tree stability of white spruce; and
- changes of tree stability characteristics of white spruce, and consequently its windfirmness, will occur as soon as 5 years after partial or total canopy removal.

The silviculture systems were specifically designed to test the range of understory protection levels from no protection to very high protection (Table 22). The intent was to compare various systems and to identify a system or systems that can

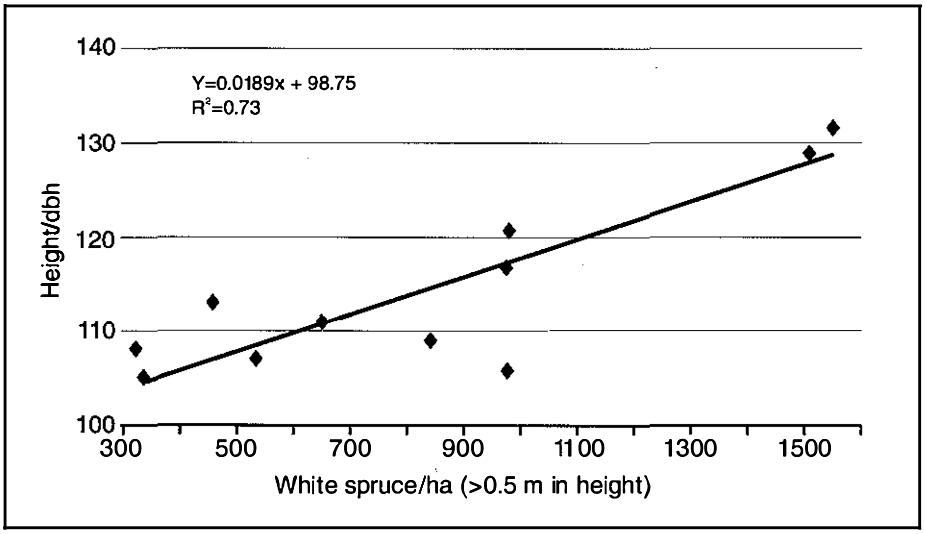

Figure 17. Linear regression of slenderness coefficient of white spruce understory trees and number of white spruce per hectare.

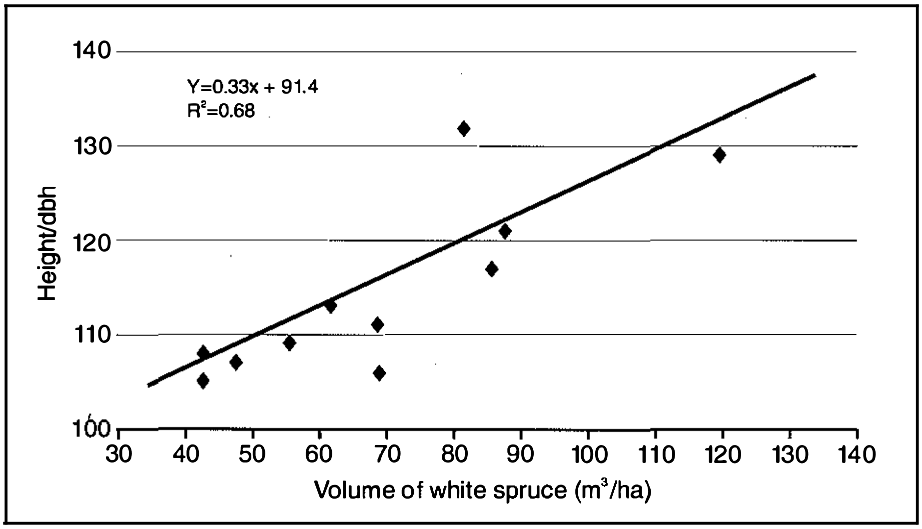

Figure 18. Linear regression of slenderness coefficient of white spruce understory trees and volume of white spruce per hectare.

prevent high incidence of windthrow under the site and wind conditions of the area. The silvicultural designs were adapted and modified to suit the harvesting technology used and to develop affordable harvesting options.

Before laying out specific in-block details, paper plans were developed, based on information obtained from 1:5000 color infrared aerial photographs. These initial plans indicated the distribution of immature spruce, topographic features that may affect harvesting and potential haul road access. In general, skidding distances were kept to less than 250 m. Each paper plan was field checked, discussed with the contractor, the company, and Alberta Land and Forest Services, and then modified when required.

Control blocks were designed to provide baseline information on equipment productivity, harvesting costs, and the effectiveness of wind protection for immature spruce, for comparison to

Table 22. Silviculture systems for reducing wind damage in white spruce understory

System	Type of protection	Level of protection	Level of harvesting difficulty	Block
Clearcut; total removal of aspen canopy	None	None	Easy	F-1-2
Clearcut; total removal of aspen canopy; some clumps of standing balsam poplar and aspen	Mutual support of neighbor trees and reduced wind speed within clumps	Low, varies with size and spatial distribution of standing residuals	Easy	Not used
Clearcut; removal of aspen canopy with retained long windbreaks of aspen/balsam poplar	Reduced wind speed on lee side of windbreaks	Medium to high, varies with permeability and distance between windbreaks	Easy	F-1-1
Alternate strip cutting in two passes	Sheltering effect of stand on windward side	High after first pass Low after second pass Varies with width of strip	Difficult Moderate Moderate	F-6-1 (50 m strips) F-6-2 (100 m strips) F-6-3 (150 m strips)
Uniform shelterwood, 50% removal of basal area	Improved stability of understory	Medium	Not compatible with feller-buncher felling	Not used
Modified uniform shelterwood, 1 pass	Improved stability of understory and sheltering effect of retained narrow strip	Very high	Moderate	F-2
Modified uniform shelterwood, 2 passes	Improved stability of understory and sheltering effect of uncut strip in the first pass	Very high after the first pass Medium after the second pass	Moderate	F-3
Combined shelterwood strip system, 2 passes	Sheltering effect and improved stability of understory	Medium to high	Moderate to difficult	F-4
Combined shelterwood strip system, 3 passes	Sheltering effect and improved stability of understory	High	Moderate to difficult	F-5-1 (50 m strips) F-5-2 (100 m strips)
Progressive strip clearcutting	Sheltering effect and height gradient of spruce deflecting wind	High	Moderate to difficult	F-7
Wedge strip cutting	Sheltering effect and height gradient of spruce deflecting wind in a wide angle of directions	Very high	Unknown	Not used

treatment blocks. Control blocks incorporated current operational practices that leave a checkerboard pattern of immature spruce standing. The feller-buncher firstfells the road and deck areas, then works its way to the block boundary and fells swaths parallel to the log deck, gradually working toward the road. When possible, the buncher creates separate bunches of deciduous and conifer stems. Bunches are laid down in lines perpendicular to the log decks. After felling, the grapple skidder skids the bunches to either deciduous or conifer log decks.

Blocks that incorporated specific features to minimize wind damage to residual immature spruce stems were harvested using a strip pattern. The strip pattern was selected because it would simplify layout and keep linear openings in the stand oriented in a north–south direction, perpendicular to the major wind direction. Also, trails running perpendicular to the log decks would minimize trail width because trail widening would not occur at intersections and curves. Skid-trail spacing was based on the effective reach of the feller-buncher (10 m), and ranged from 20-40 m apart. All skid-trails were flagged before felling.

Felling began at the decking area and progressed into the trails. Bunches were laid beside the feller-buncher tracks or off the trail in aspen clumps. When the buncher reached the boundary, it turned around and traveled to the next trail, where it repeated the pattern. The grapple skidder skidded the bunches on the deck area and pulled the bunches from the trails onto the log decks. When the trailed bunches had been skidded, the buncher returned to the end of the trail and began felling all the merchantable stems it could reach without leaving the trail, working its way to the log deck. Bunches were laid in a shingle pattern on the trail. After the strips were felled, the grapple skidder returned and skidded all the bunches to the log deck.

It was not possible to separate deciduous and conifer log decks during skidding because of the confined decking areas at the treatment blocks. The delimber sorted the conifer stems from the deck during delimbing, and set them aside, either in separate small decks, or laid across the delimbed deciduous log deck.

The equipment used to harvest all the blocks consisted of a Caterpillar EL300 feller-buncher with a 55.9 cm Koering high-speed saw felling head, a John Deere 648D grapple skidder, and a Lim-mit LM2200 roll-stroke delimber mounted on a Caterpillar DL300B carrier. In addition, a prototype, zero tailswing feller-buncher, the Mountain Cat, was demonstrated on a portion of block F-6-1, and a Caterpillar 518 grapple skidder was used to supplement skidding.

Harvesting Cost and Productivity Studies

Shift-level time and production information was collected daily using a model DSR Servis recorder mounted on the feller-buncher, delimber, and grapple skidders. The FERIC researcher noted the reasons for equipment delays greater than 15 minutes directly on the DSR charts, and daily work patterns and observations in a diary. 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 nonproductive. A shift with any amount of production time was classified as a productive shift. A nonproductive shift was classified as one that was originally scheduled for production, but some event (such as repairs or a lack of wood or the lack of an operator) prevented the machine from working. Scheduled shifts-off included weekends and statutory holidays.

Total time for shifts with production were further subdivided into three categories: 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 either operational delays such as planning, which was a routine delay required to complete the work, or operator delays, such as when the operator left his machine for personal reasons.

Throughout the harvesting studies the FERIC researcher also conducted detailed work-sampling studies for each machine. This information will be summarized and will provide a breakdown of cycle times that indicated changes in work patterns from one harvesting method to another.

Prescriptions by Block, Project 8032

Block F-1-1

Treatment: One-Pass Control/Modified Uniform Shelterwood

Prescription: This is a combination treatment to demonstrate the adaptation of treatment to varied within-block spruce stocking and to adopt a windbreak approach that minimizes the sacrifice of merchantable deciduous volume.

Harvest was done in late winter 1994, using current operational practices in areas where immature spruce stocking was low-to-moderate. The harvesting was done in one pass, providing no wind protection, or minimal wind protection in the west (windward) edge of the cutblock. A perimeter boundary was felled. On areas where immature spruce stocking was moderate-to-high, machine corridors were established at 25 m intervals perpendicular to the prevailing wind. All accessible deciduous volume was removed in one pass, leaving a 5 m uncut strip midway between corridors. Machine corridors, roads, and landings should result in the removal of about 40% of the forest cover from the block. About 15% of the merchantable deciduous will be sacrificed in the 5 m buffer strips. This should provide repetitive windbreak effects and result in a medium-to-possibly high-level of wind protection for immature spruce. Figure 19 shows the harvest plan and a view of the block before and after harvest.

Block F-1-2

Treatment: One-pass Control Harvest

Prescription: Harvest was done in late fall 1993, using current operational practices modified by using no perimeter harvest and operational "avoidance" procedures to protect immature spruce while removing merchantable deciduous overstory stems in one pass at year 0. This provided minimal wind protection for immature spruce only in the narrow band adjacent to the west (windward) edge of the cutblock. Figure 20 shows the harvest plan and a view of the block before and after harvest.

Block F-2

Treatment: One-Pass Modified Uniform Shelterwood

Prescription: Harvest was done in fall 1993, using a one-pass modified uniform (extensive) shelterwood system with all accessible merchantable deciduous volume removed between machine corridors spaced 30 m apart, leaving 10 m of uncut deciduous as a buffer midway between corridors. Machine corridors, roads, and landings removed about 40% of the forest cover in the block. About 30% of the merchantable deciduous on the block was sacrificed in uncut 10 m buffers between machine corridors. These uncut bands are expected to result in a high level of wind protection for immature spruce. Wind buffers were incorporated into deck areas to ensure that unprotected length did not exceed 200 m. Figure 21 shows the harvest plan and a view of the block before and after harvest.

Block F-3

Treatment: Two-Pass Modified Uniform Shelterwood

Prescription: Harvest was done in fall 1993, using a two-pass modified uniform (extensive) shelterwood system with all accessible merchantable deciduous volume removed between machine corridors spaced at 40 m in the first pass, the remainder to be removed from machine corridors cut between first-pass corridors at year 0+5. Machine corridors, roads, and landings removed about 40% of forest cover from the block. This treatment is expected to provide a very high level of wind protection created by the sheltering effects of the uncut 20 m strip between the first and second harvests. During this time (about 5 years) immature spruce stability will improve because of exposure to light and wind stimulus. This improved stability of spruce is expected to result in a medium level of wind protection after removal of overstory strips in the second pass. Wind buffers were incorporated into deck areas to ensure that unprotected length did not exceed 200 m. Figure 22 shows the harvest plan and a view of the block before and after harvest for each pass.

Block F-4

Treatment: Two-Pass Strip Shelterwood

Prescription: Harvest was done in winter 1994, using a two-pass strip shelterwood system that includes four segments (A, B, C, and D) each with four strips (1, 2, 3, and 4). Each segment had 50% of its merchantable deciduous volume removed between machine corridors in strip 1 and 100% in strip 2 in year 0, and will have 50% of the merchantable deciduous volume removed between machine corridors in strip 3 and 100% of strip 4 removed in year 0+5. All strips are 50 m wide. No strip is entered more than once, in contrast to F-5-1. This is expected to provide a medium–high level of wind protection for immature spruce through the combined benefits of sheltering effects in narrow strips and partial removal of overstory in every second strip. The result will be increased wind stability of

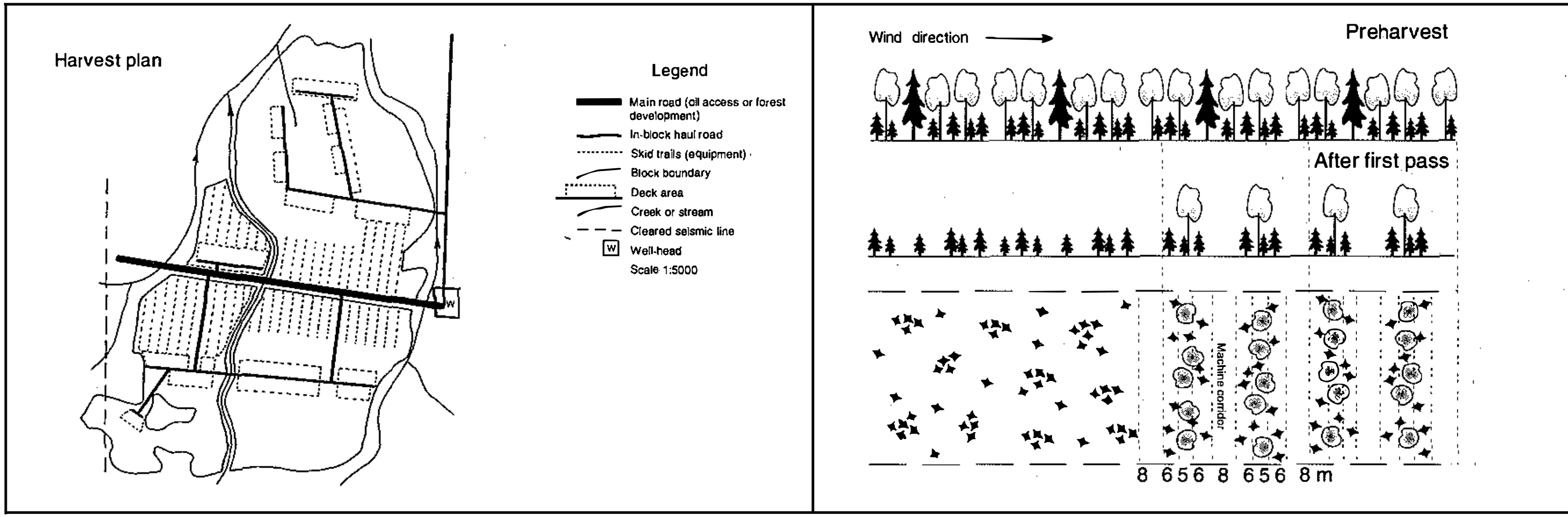

Figure 19. Harvest plan and view of block F-1-1 before and after harvest (one-pass control modified uniform shelterwood).

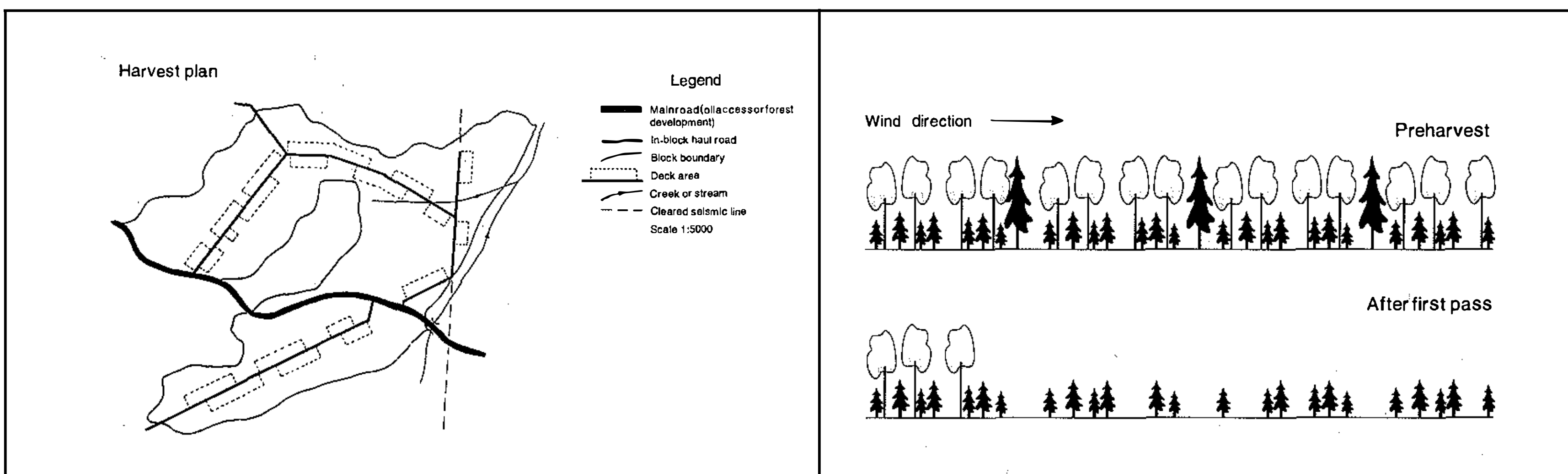

Figure 20. Harvest plan and view of block F-1-2 before and after harvest (one-pass control).

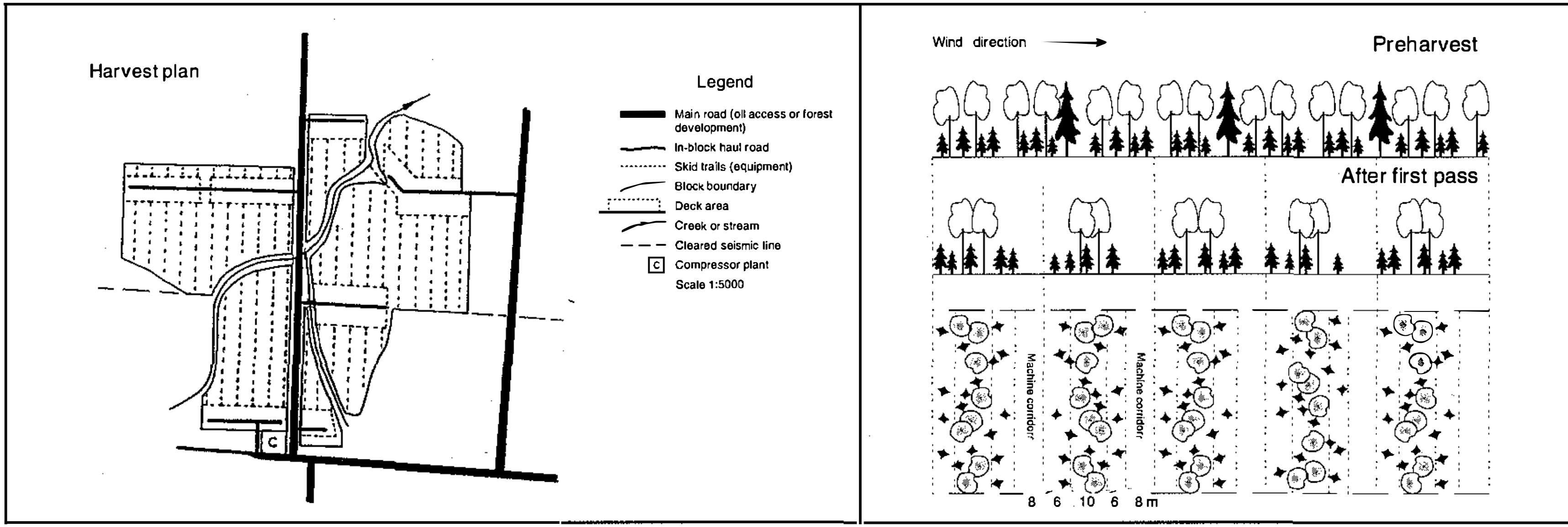

Figure 21. Harvest plan and view of block F-2 before and after harvest (one-pass modified uniform shelterwood).

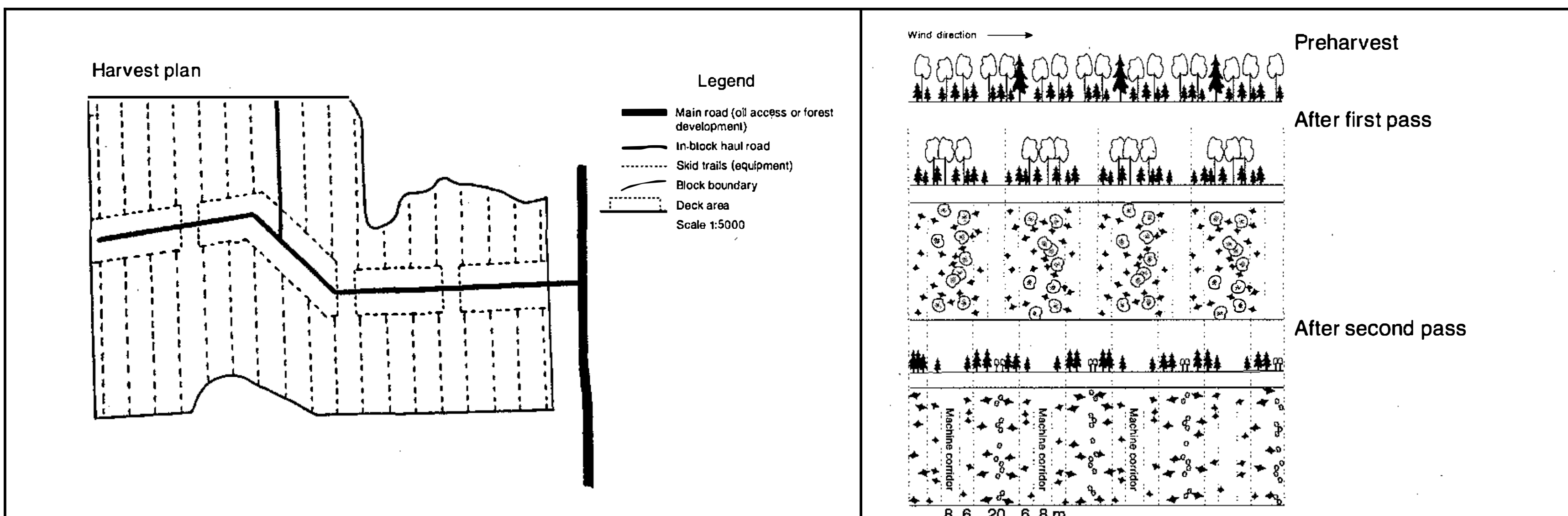

Figure 22. Harvest plan and view of block F-3 before and after harvest for each pass (two-pass modified uniform shelterwood).

spruce because of greater exposure to light and wind stimulus. Figure 23 shows the harvest plan and a view of the block before and after harvest, for each pass.

Block F-5-1

Treatment: Three-Pass Strip Shelterwood

Prescription: Harvest was done in winter 1994, using a three-pass strip shelterwood system that includes four segments (A, B, C, and D) each with four strips (1, 2, 3, and 4). Each segment had 50% of its merchantable deciduous volume removed between machine corridors in strip 1 and 100% in strip 2 in year 0. Removal of the remaining volume of strip 1 and 50% of strip 3 is at year 0+5, and removal of remaining volume in strip 3 and all of strip 4 at year 0+10. All strips are 50 m wide. This is expected to provide a high level of wind protection for immature spruce because of the combined effects of sheltering in narrow strips, improved tree stability through gradual removal of overstory, and windbreak effects from uncut strips remaining after the second pass. Figure 24 shows the harvest plan and a view of the block before and after harvest, for each pass.

Block F-5-2

Treatment: Three-Pass Strip Shelterwood

Prescription: Harvest was done in early fall 1993, using a three-pass strip shelterwood system that includes two segments (Aand B) each with four strips (1, 2, 3, and 4). Each segment had 50% of its merchantable deciduous volume removed between machine corridors in strip 1 and 100% in strip 2 in year 0. Removal of the remaining volume of strip 1 and 50% of strip 3 is at year 0+5, and the remaining volume of strip 3 and all of strip 4 at year 0+10. All strips are 100 m wide. This is expected to provide a high level of wind protection for immature spruce because of the combined effects of sheltering in narrow strips, improved tree stability through gradual removal of overstory, and windbreak effects from uncut strips remaining after the second pass. In comparison to F-5-1, the level of protection will be somewhat lower because the strips are wider (100 m as compared to 50 m). Figure 25 shows the harvest plan and a view of the block before and after harvest, for each pass.

Block F-6-1

Treatment: Two-Pass Alternate Strip (50 m)

Prescription: Harvest was done in early fall 1993, using a two-pass strip system that includes six segments (A, B, C, D, E, and F) each with two strips (1 and 2). All merchantable deciduous volume in strip 1 was harvested in year 0 and all merchantable volume in strip 2 will be harvested in year 0+5. All strips are 50 m wide. A medium level of wind protection for immature spruce is expected because of the sheltering effects of narrow strips in the years between the first and second pass. After the second pass, the level of protection will be low to very low because of the large open area, which is 300 m wide. Figure 26 shows the harvest plan and a view of the block before and after harvest, for each pass.

Block F-6-2

Treatment: Two-Pass Alternate Strip (100 m)

Prescription: Harvest was done in winter 1994, using a two-pass strip system that includes four segments (A, B, C, and D) each with two strips (1 and 2). All merchantable deciduous volume in strip 1 was harvested in year 0 and all merchantable deciduous volume in strip 2 is to be harvested in year 0+5. All strips are 100 m wide. A low to medium level of wind protection for immature spruce is expected from the wider strips in the years between the first and second passes. After the second pass the level of protection will be very low, especially in second-pass strips, because the large open area of 800 m in the direction of prevailing winds. Figure 27 shows the harvest plan and a view of the block before and after harvest, for each pass.

Block F-6-3

Treatment: Two-Pass Alternate Strip (150 m)

Prescription: Harvest was done in early fall 1993, using a two-pass strip system that includes four segments (A, B, C, and D) each with two strips (1 and 2). All merchantable deciduous volume in strip 2 was harvested in year 0 and all merchantable deciduous volume in strip 2 is to be harvested in year 0+5. All strips are 150 m wide. A very low level of wind protection for immature spruce is expected in the years between the first and second passes because of the wide strips, with low to medium protection in the bands along the windward edges of the strips. After the second pass, a critically low to very low level of protection is expected because of the large open area of 1200 m, oriented in the prevailing wind direction. Depending on the monitored incidence of wind damage, windbreak strips may need to be retained in the 150 m strips of the second pass. Figure 28 shows the harvest plan and a view of the block before and after harvest, for each pass.

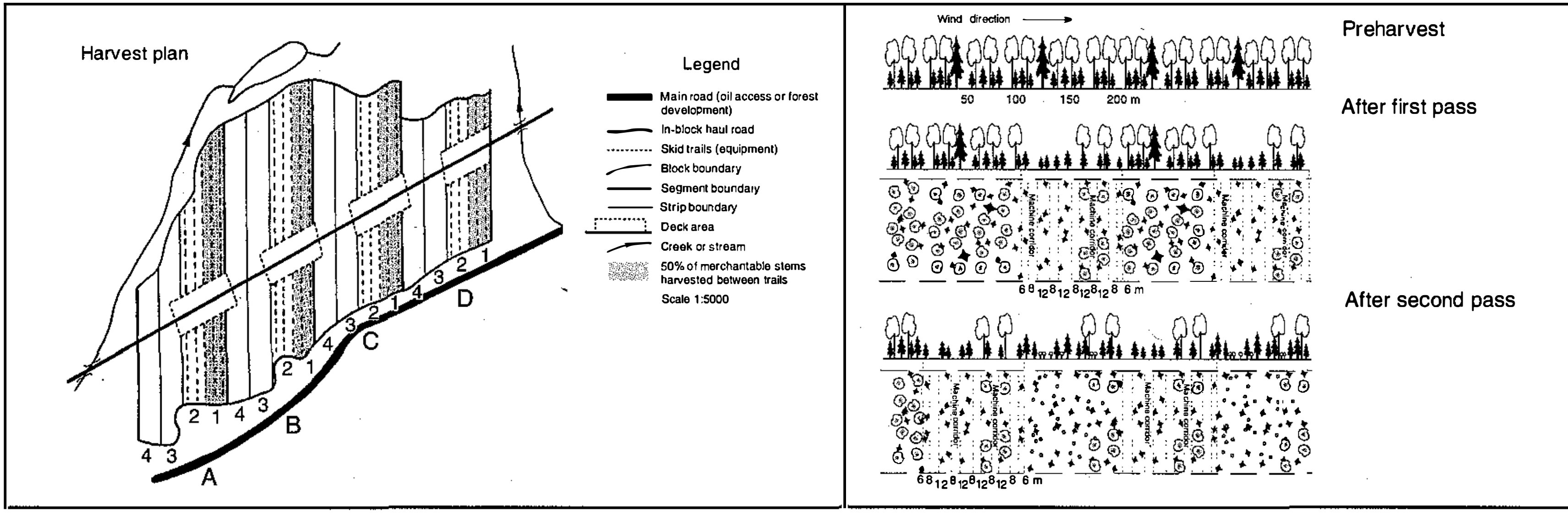

Figure 23. Harvest plan and view of block F-4 before and after harvest for each pass (two-pass strip shelterwood [50 m]).

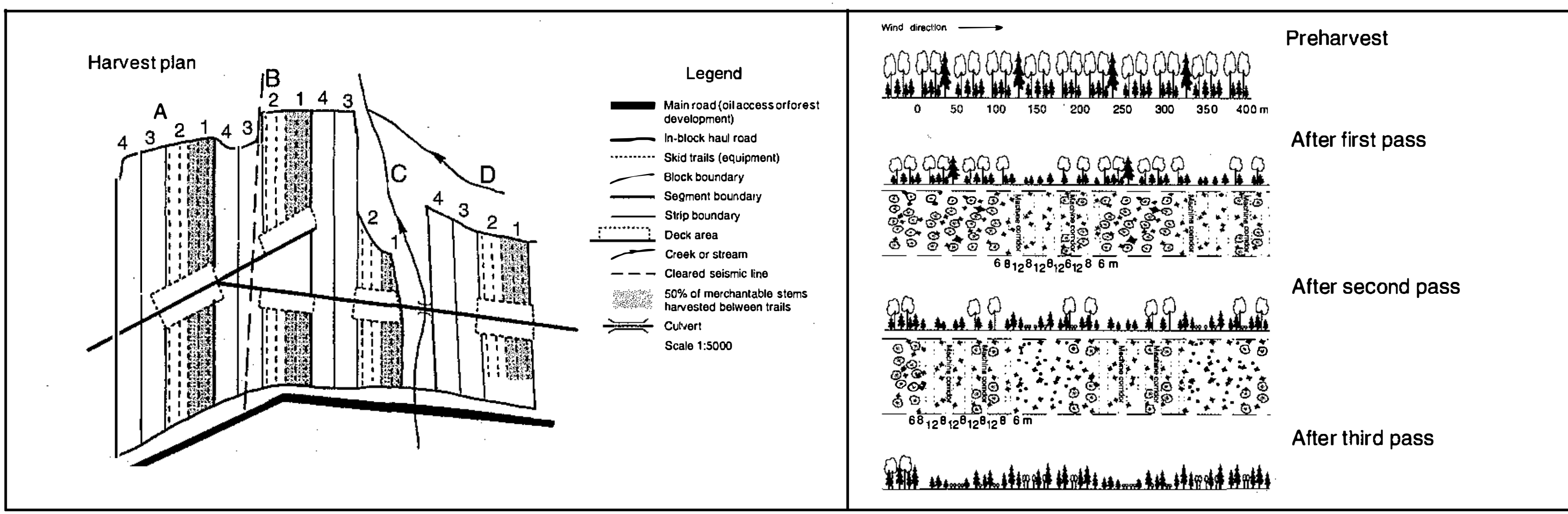

Figure 24. Harvest plan and view of block F-5-1 before and after harvest (three-pass strip shelterwood [50 m]).

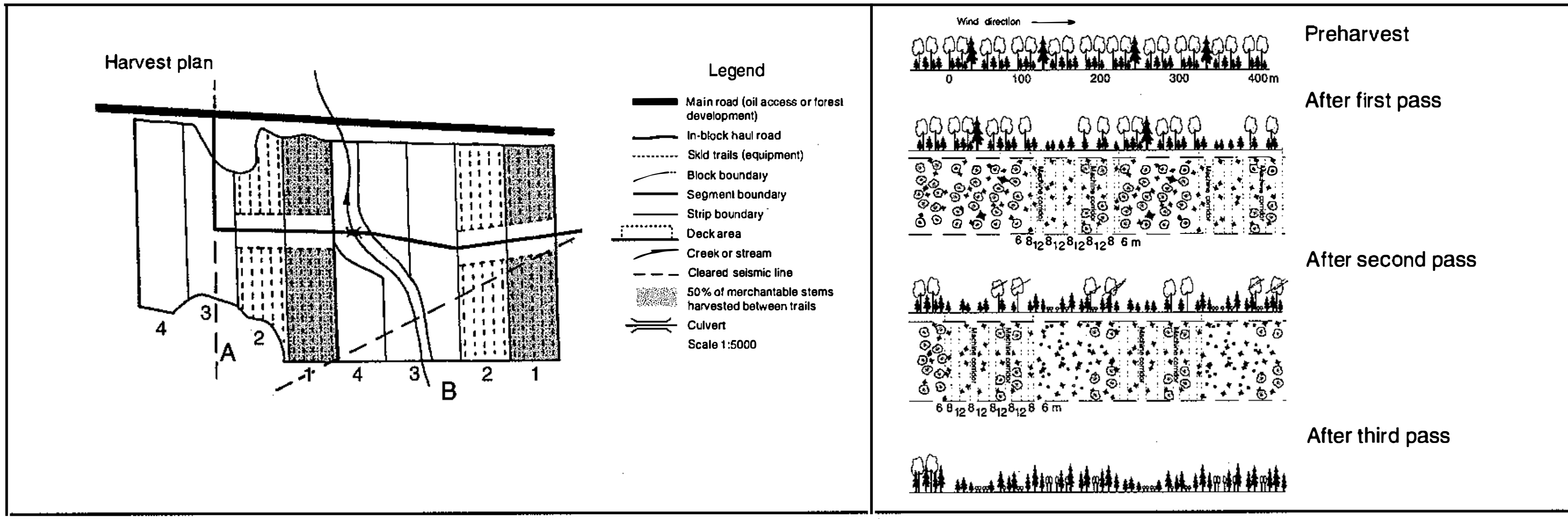

Figure 25. Harvest plan and view of block F-5-2 before and after harvest for each pass (three-pass strip shelterwood [100 m]).

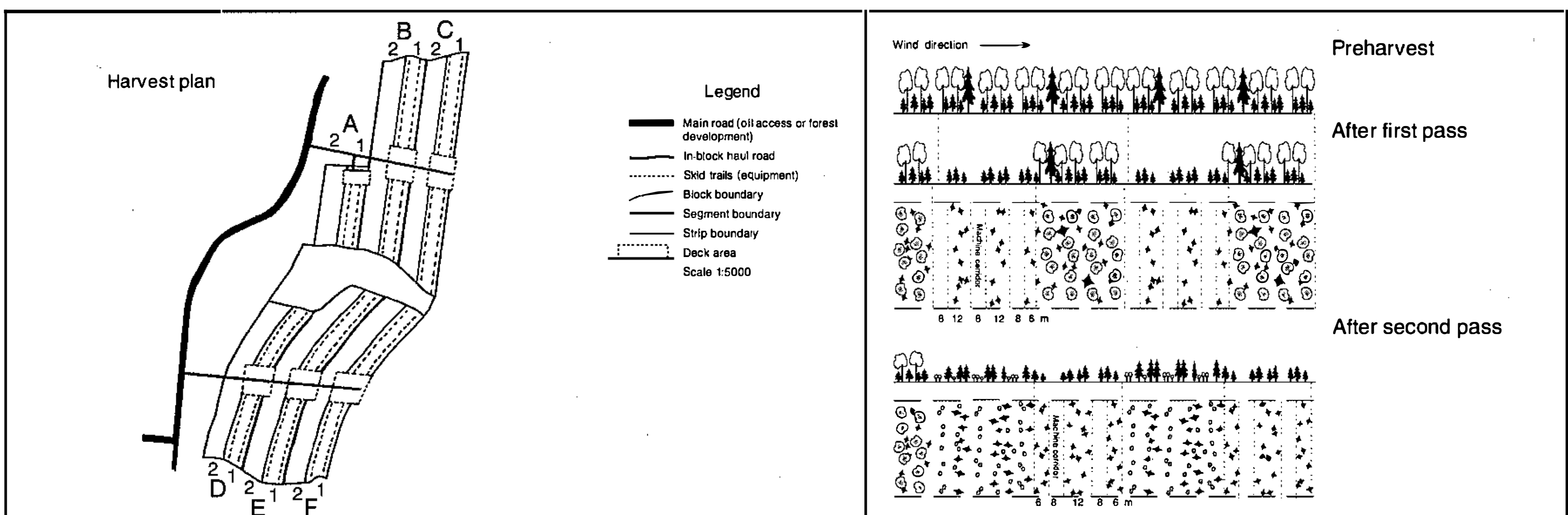

Figure 26. Harvest plan and view of block F-6-1 before and after harvest for each pass (two-pass strip alternate strip [50 m]).

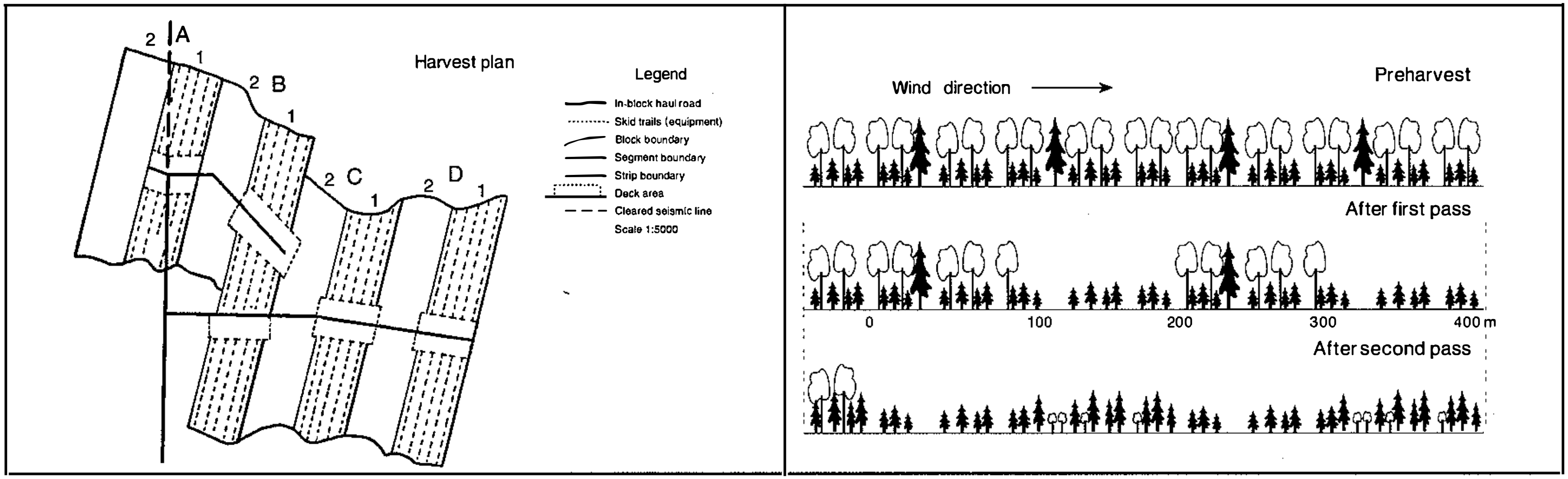

Figure 27. Harvest plan and view of block F-6-2 before and after harvest for each pass (two-pass alternate strip [100 m]).

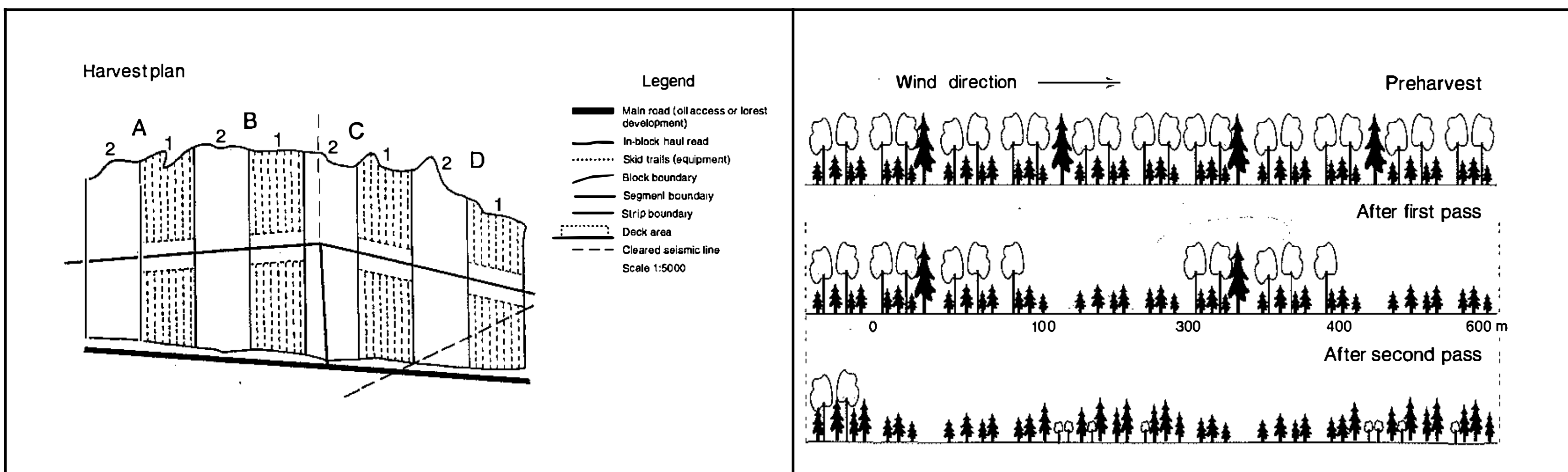

Figure 28. Harvest plan and view of block F-6-3 before and after harvest for each pass (two-pass alternate strip [150 m]).

Block F-7
Treatment: Four-Pass Progressive Strip

Prescription: Harvest was done in late winter 1994, using a four-pass progressive strip system that includes four segments (A, B, C, and D) each with four strips (1, 2, 3, and 4). All merchantable deciduous volume will be harvested in each pass. Strip 1 was harvested in year 0; strip 2 in year 0+5; strip 3 in year 0+10, and strip 4 in year 0+15. All strips are 50 m wide. A very high level of wind protection to immature spruce will be provided by narrow strips, gradual exposure of residual spruce to wind, and a height gradient of spruce (decreasing heights) against wind direction. Figure 29 shows the harvest plan and a view of the block before and after harvest, for each pass.

PROJECT 8032, PRELIMINARY RESULTS

Harvesting Operations

Table 23 shows area harvested and total and unit area volume removed, by treatment.

To date, data from harvesting studies have not been analyzed. The following observations summarize some points identified by the researchers during harvesting.

1. Decreased felling productivity on the treatment blocks raised harvesting costs. The feller-buncher's productivity was reduced because it had to spend more time traveling between working sites, and because operators spent more time placing the head between immature spruce stems. In addition, the operating cycle of the feller-buncher requires more travel while carrying loads, increasing stress on the felling head and travel components ultimately leading to increased repair costs and reduced feller-buncher life.

2. Feller-buncher operators liked following flagged trails. All operators felt felling productivity would have been less and fewer immature stems would have been protected if operators had had to find their own trails.

3. Narrow, 50 m strip widths appeared to further decrease feller-buncher productivity, because the buncher spent a greater proportion of time traveling between strips. Also, the decking area was confined and additional uncut areas next to the strip had to be felled to provide operating room.

4. Although the feller-buncher was large, and it required a relatively wide cleared trail to operate on, it could lift any tree that was cut and place it in a bunch, even at maximum (10 m) reach, and worked well in the study blocks.

5. Trail width, trail length, and feller-buncher reach are the most important factors in maximizing the amount of area left undisturbed by harvesting equipment (Fig. 30). However, trail width can never be less than the width of the widest equipment using the trails or the width of crowns of skidded trees. The trail length is governed by the amount of wood that can be decked at roadside.

6. Feller-buncher operators are the key to successfully protecting immature spruce stems while minimizing productivity reductions. However, some operators, even when paid on an hourly basis, do not like the increased concentration and stress that occurs as a result of modifying their felling practices. Operators found they enjoyed doing specific tasks. For example, one operator liked felling trails, whereas another enjoyed felling trees between the trails.

7. If the operational protection of immature spruce stems is to increase significantly, contractors and operators must be reimbursed for the additional costs and work required.

8. Decking area, and the area heavily affected by skidder traffic around the deck, appeared to be much smaller on the trailed blocks than on control blocks.

9. It is impractical to develop decking areas on one side of a haul road if stems are delimbed using a stroke delimber. Long, delimbed logs extend out the back of the delimber, which requires a cleared area for operation.

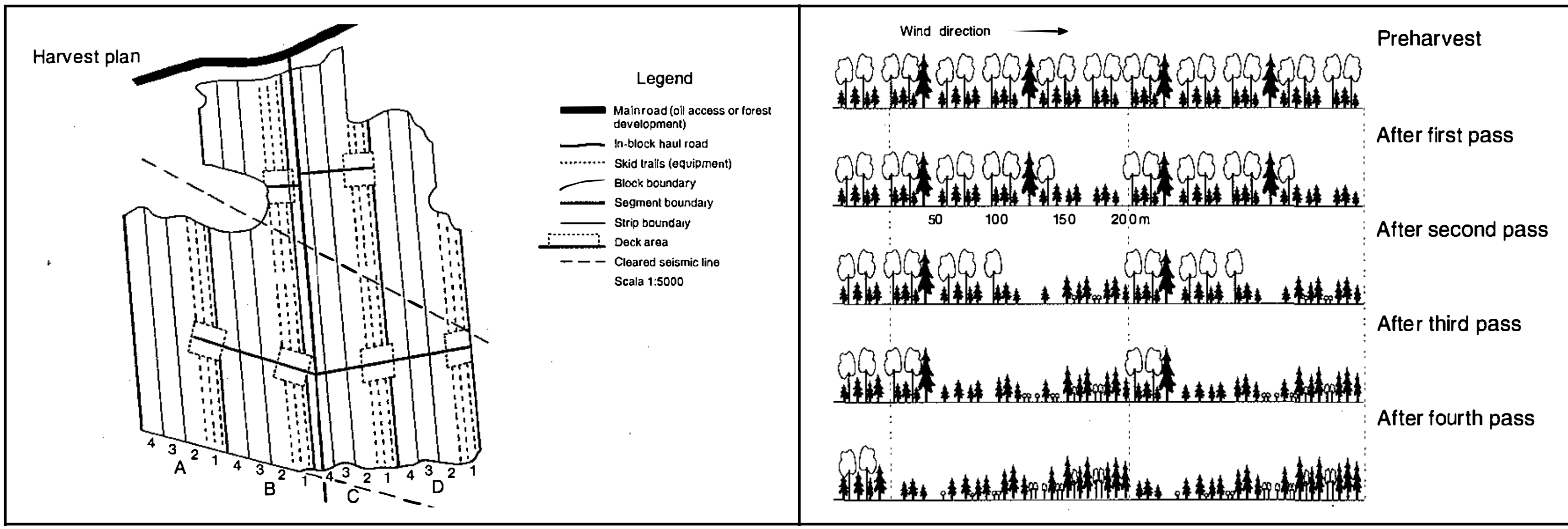

Figure 29. Harvest plan and view of block F-7 before and after harvest for each pass (four-pass progressive strip [50 m]).

Table 23. Area harvested and total volume removed by treatment

Block	Gross area[a] (ha)	Harvested area[b] (ha)	% of block cut	Deciduous		Conifer		Total	
				Va[c] (m^3)	Va/HA[d] (m^3/ha)	Va (m^3)	Va/HA (m^3/ha)	Va (m^3)	Va/HA (m^3/ha)
F-1-1	59.0	55.7	94	12 000[e]	215	1 000[f]	18	13 000	233
F-1-2	61.0	61.0	100	13 657	224	2 109	35	15 766	258
F-2	28.0	21.4	76	4 822	225	139	6	4 961	231
F-3	35.0	21.2	61	3 629	171	233	11	3 862	182
F-4	36.0	18.6	52	3 475	187	95	5	3 570	192
F-5-1	40.0	17.6	44	3 585	204	91	5	3 676	209
F-5-2	32.0	18.3	57	3 104	170	345	19	3 449	189
F-6-1	25.0	11.4	36	1 988	174	636	56	2 624	230
F-6-2	38.0	21.2	56	2 600[e]	123	464[e]	22	3 064	145
F-6-3	67.0	29.1	43	6 747	232	811	28	7 558	260
F-7	61.0	16.0	26	2 700[e]	169	300[e]	19	3 000	188
Total	482.0	291.5		58 307	200	6 223	21	64 530	221

[a] Area of entire cutblock.
[b] Area harvested in the first pass, including access roads.
[c] Va = actual volume from log yard scale.
[d] HA = harvested area.
[e] No logs hauled from block-estimated volume.
[f] 262 m^3 of conifer logs hauled, estimate 738 m^3 remaining to be hauled.

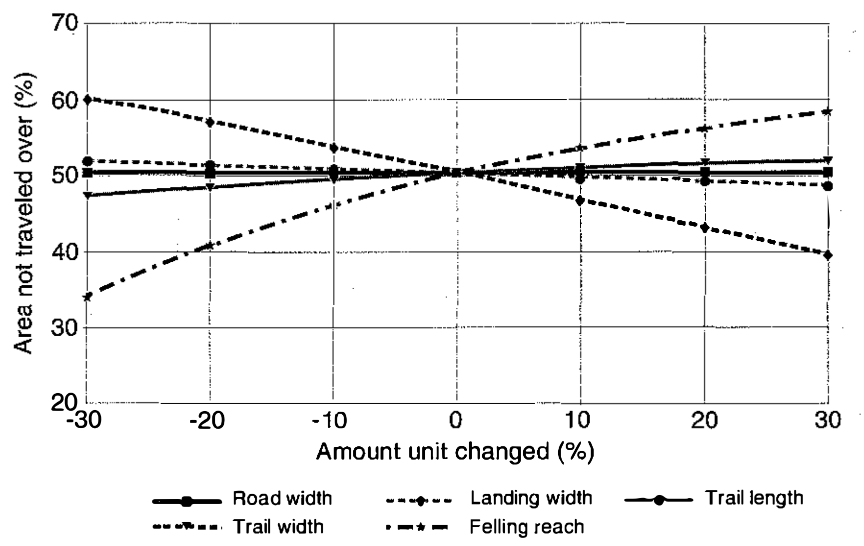

Figure 30. Effect changing individual model parameters has on the proportion of cutblock area not traveled over by harvesting equipment (based on a 10 m road width; a 35 m landing width; an 8.5 m skid-trail width; a 10 m feller-buncher reach; and a 250 m skid-trail length).

10. Maximum skid distance is limited by the capacity of the deck areas. In general, trails that were between 200–250 m long and that recovered all merchantable volume were satisfactory. Fewer logs were decked when only a portion of the merchantable deciduous volume was harvested. Skidding productivity did not appear to decrease significantly at longer distances, because trails were free of obstacles and provided fast skidder travel.

11. Felling operations that protect significant numbers of immature spruce stems can be undertaken at night and during the winter harvest season. Felling between trails could be undertaken during the day or night, but operators seemed to do a better job during daylight. Felling trails was relatively easy at night because operators followed the flagging. However, night felling was difficult when it was snowing or when dry snow was held in tree branches. In these conditions, the lights used to illuminate the work area reflected off the falling snow, creating a white fog that prevented the operator seeing the work area.

12. Although all the blocks had been extensively planned before harvesting operations began, during harvesting plans were sometimes modified to improve operating efficiency or to achieve better results. These modifications were successfully implemented because of the flexible approach and continuous interaction among researchers, contractor, licensee, and Alberta Land and Forest Services.

Wind Damage in Block F-6-3

Considerable windthrow occurred in Block F-6-3 (a block cut in 150 m wide strips) soon after it was harvested. Felling was completed by September 16, 1993, and windthrow was evident on aerial photographs taken October 11, 1993. Additional windthrow damage was observed on 35 mm aerial photographs taken November 11, 1993. The progression of wind damage will be assessed using fall 1993 and spring and fall 1994 aerial photographs and, thereafter, using aerial photographs taken annually.

Using the October 11 aerial photography, the recognizable windthrow damage was evaluated by noting the distance of each fallen tree from the west edge of a strip and the orientation of windthrow. Photointerpretation was done by examining stereo pairs of transparent color aerial photographs taken at a scale of 1:7500 and projected at about 1:2000. Windthrown trees were sketched and their distances from the strip edge and windthrow direction measured on cutblock overlays.

An example of the spatial distribution of windthrown spruce in a strip is shown in Figure 31. For the analysis, the data were pooled from all four strips. The influence of distance from the windward edge is shown in 10 m distance classes in Figure 32. Out of the total sample of 120 windthrown spruce trees on four strips, none were found in the distance 1–20 m from the west edge of the strip. About 10% of damage occurred in the distance 21–70 m from the west edge of the strip. From 70 m on, the incidence of windthrow gradually increased to a peak at between 111 and 120 m from the west edge. Thereafter the incidence of damage decreased to minimal in the last 20 m in front of the east edge of strips.

In the following simplified interpretation of wind behavior, clear-cut strips may be considered to be open areas. When winds leave the forest stand on the windward side of a clear-cut strip, their speed accelerates through the open areas of the strip. Wind speeds decrease as the edge of the uncut stand on the lee side of the clear-cut strip is approached. The observed spatial distribution of windthrow in the strips of Block F-6-3 appears to conform to the general pattern of wind behavior described.

The orientation of windthrown trees, differentiated by azimuth classes, is shown in Figure 33. The most frequent orientation of thrown trees was in the azimuth 91–120° range, followed closely by azimuth 121–150°. This indicates that the winds causing most of the damage (approximately 73%) came from the prevailing direction of west and/or northwest. The main orientation of windthrows seems to correlate well with the direction of the maximum winds recorded in the region in the fall of 1993. It should be noted that the difference of 25–50° in wind throw could easily have been due to the channeling influence of open landings and a torque at the base of the tree.

In this preliminary analysis no attempt was made to determine the relative incidence of damage in the total area of strips. The sample of 120 fallen trees detected on aerial photographs very likely contained trees that had been damaged by harvesting and consequently could have been blown over by low-speed winds. Neither was any attempt made to relate the observed damage to the occurrence of specific winds. Wind speed and gusts in forested landscape are subject to very complex factors, including the turbulence influenced by stand aerodynamics, layout of cutblocks, and topography. As a result, wind patterns are highly unpredictable. From the inference that follows it can be concluded that the general wind conditions in the area in the fall of 1993 were conducive to extensive windthrow.

Extreme wind speeds were measured at the project location and at the Manning airport. At the project site a wind tower was placed in the clearcut block CC-4 immediately west of the treatment block F-7, and wind speeds were measured at 10 and 15 m heights. The Manning airport site was selected to help relate the wind extremes observed at the project site to the closest weather station and possibly to other weather stations in the climatological network.

Over the observation period (October 9, 1993–March 8, 1994) there were 12 days at the project site and 17 days at Manning airport in which wind gusts exceeded 50 km/hr at either the 10 or 15 m height. The gust speeds and associated wind direction for both the project site and the Manning airport station are listed in Table 24. The maximum gusts exceeding 50 km/hr measured at the Peace River airport in September 1993 are shown in Table 25.

The maximum wind speed recorded at the project site was 80.6 km/hr on November 14, 1993 at the 15 m level. On the same day the maximum wind speed recorded at the Manning airport station was about 15 km/hr higher than that recorded on the project site (96.5 km/hr about 20 minutes after the highest gust measured at the trial site). The maximum wind speed recorded at Peace River airport for November 14, 1993 was 61 km/hr from the west.

Even though greater wind speeds were recorded at the Manning airport station than at the project site, a comparison of all the daily maximum gusts shows there was a close correlation between the two sites. This seems to indicate that wind extremes measured at the Manning weather station will be spatially representative of wind conditions on the project site (Flesch and Wilson 1994).

Climatologically, the maximum gusts measured on November 14, 1993 at all three locations—the project site, Manning airport weather station, and Peace River airport—can be classified as important, extreme events, given the return periods of extreme winds for the region calculated by Flesch and Wilson (1993): Peace River, 2 year return period: 85 km/hr; 5 year return period: 92 km/hr.

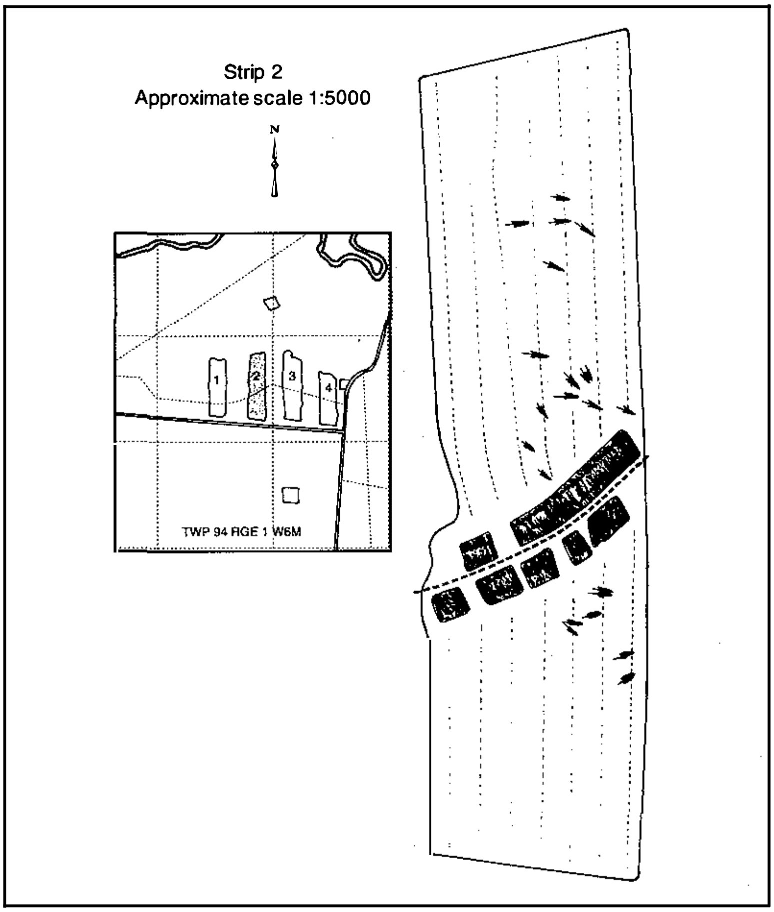

Figure 31. Spatial distribution of windthrown spruce in strip 2 of block F-6-3.

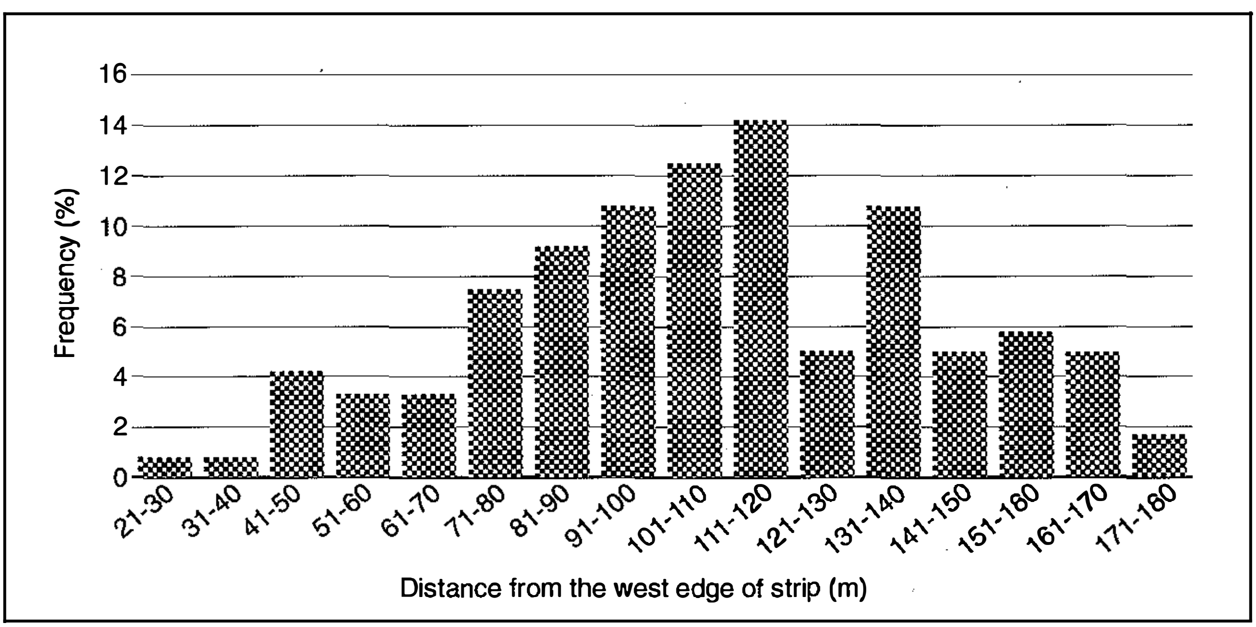

Figure 32. Relative frequency of windthrown trees in distance class, block F-6-3 (sample size = 120).

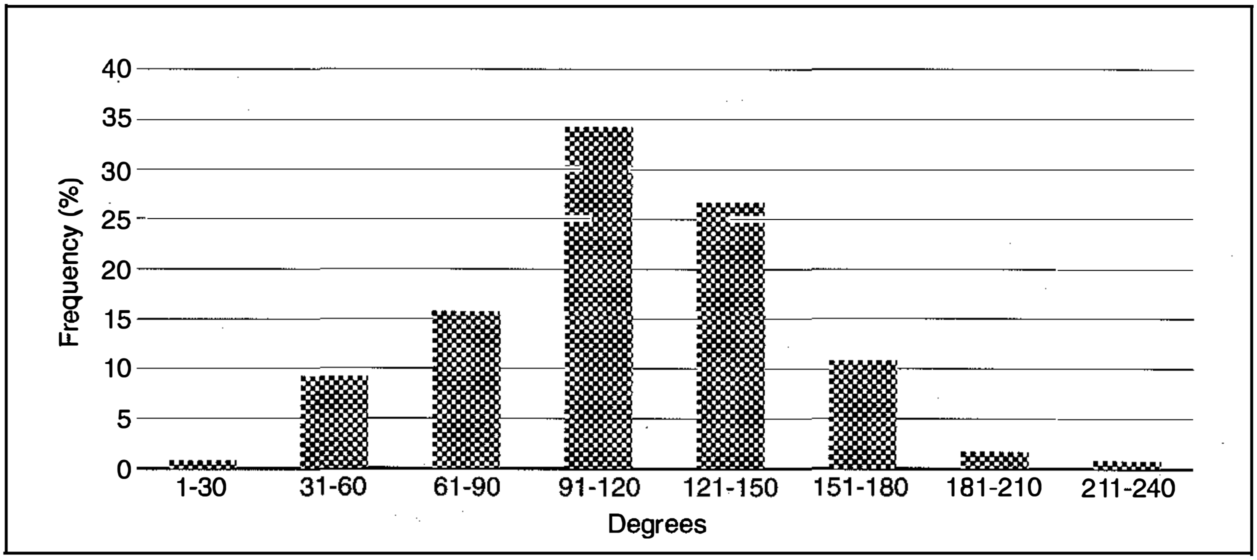

Figure 33. Relative frequency of windthrown trees in azimuth classes, block F-6-3 (sample size = 120).

Table 24. Wind gusts over 50 km/h at the project site and Manning airport

Date	Project site			Manning airport	
	Speed (km/h)		Direction	Speed (km/h) @	Direction @
1993–94	@ 10 m ht	@ 15 m ht	@ 15 m ht	8.5 m ht	8.5 m ht
Oct. 19	56.2	56.2	NW	50.4	W
26	53.3	63.7	SW	73.8	W
27	47.5	47.9	NW	52.2	NW
Nov. 3	50.4	50.4	N	52.2	N
14	73.4	80.6	W	96.5	W
18	41.8	39.6	NW	54.0	NW
19	61.9	60.8	W	74.2	SW
20	47.5	44.6	N	72.7	SW
26	47.5	54.0	W	43.6	SW
Dec. 3	47.5	45.0	W	51.8	W
10	41.8	42.8	SW	55.4	W
11	44.6	44.3	W	64.8	W
19	59.0	58.3	NW	60.8	NW
20	76.7	74.2	NW	77.4	NW
Jan. 8	47.5	46.8	NW	51.1	NW
Mar. 1	64.8	61.9	SW	65.2	W
3	47.5	50.8	W	46.8	W
4	47.5	52.9	W	56.5	SW
5	61.9	63.4	W	58.0	SW

Source: Flesch and Wilson (1994).

Table 25. Wind gusts over 50 km/h at the Peace River airport in September 1993

Date	Max gust (km/h)	Direction
Sept. 2	76	NW
8	56	NW
11	50	N
26	63	W
29	76	W

It follows, then, that the blocks with silvicultural systems that called for harvesting before mid-November were exposed to extreme wind events, and that the residual spruce stands in each silvicultural system were adequately tested for resistance to damage. An assessment of the damage from the 1994 spring aerial photography should show the first evidence of the differential levels of protection provided by the silvicultural and harvesting options being tested.

Future Treatments, Surveys, and Research and Development

Table 26 summarizes a desirable schedule for future treatments, surveys, and research and development on the project area. Although the total life of the project is 20 years, much of the information crucial to assessing and reducing wind damage to residual spruce and assessing deciduous regeneration and mixedwood growth and yield will be obtained over the next 5 to 10 years and reported by the end of the 1999 and 2004 monitoring and assessment periods.

In order to maximize the potential benefits from this project it is suggested that:

- five-year priority be given to the second harvest pass, wind damage assessment, aspen regeneration, and wind behavior research, and that short-term technology transfer be focused on planning and establishment;
- ten-year priority be given to wind damage assessment, growth and yield measurements, and longer-term technology transfer focused on results; and
- priorities for project continuation beyond 10 years should be set with reference to the relevance of 5 and 10 year results to forest management priorities at that time; because of the long-term nature of growth and yield assessment, plot remeasurements for that purpose would be of particular value beyond 10 years.

SUMMARY AND CONCLUSIONS

Projects 1480 and 8032 were designed to test silvicultural prescriptions that will protect immature (understory) white spruce during the harvest of mature aspen overstories, using modified conventional harvesting systems. The projects present mixedwood management strategies as potential alternatives to traditional conifer management, recognizing a range of coniferous and deciduous regeneration, stocking, growth, and yield. They place understory spruce protection within the context of extensive mixedwood ecosystem management, with potential for affordable, ecologically sound strategies compatible with current priorities on alternatives to clear-cutting, maintenance of biodiversity, and long-term sustainability of boreal ecosystems. Such management strategies raise questions of technical feasibility and costs and have implications for operational ground rules, land base classification and change, and mixedwood stocking, performance standards, and growth and yield methodologies.

A two-stage harvesting and tending stand-level model was adopted as the basis for silvicultural prescriptions upon which treatments described in this report were based. The model is designed to accommodate two harvests of aspen and one harvest of spruce in a 110-year cycle.

Project 1480

Harvesting

The harvesting component of Project 1480 documented a study of roadside and cut-to-length harvesting equipment working in mixedwood stands. It compared costs, productivities, and

Table 26. Future harvests, surveys, and R&D

Item	Timing	Function	Agency[a]
1. Second, third, and fourth harvest passes	1999, 2004, and 2009	Complete treatment schedule for each silvicultural prescription; preceed with pre-harvest transect measurement	DMI, LFS, FERIC
2. Leaf-off color aerial photography at 1:7500	Spring and fall 1994; spring 1995 to spring 2014; 5 times for each pass (20 years)	Spruce wind-damage assessment, stratification of spruce residual by density and distribution, and selection of long-term transect sample plots (TSPs) for growth and yield measurement	LFS, CFS
3. Wind damage analysis	Spring 1994 to spring 2014 (20 years)	Rate silvicultural and harvesting prescriptions for spruce wind-damage reduction and report results	LFS, CFS
4. Post-harvest transect plot remeasurments	Spring 1994, 1999, and 2009, then 5 years after each harvest pass (20 years)	Growth and yield measurements for each treatment, on selected TSPs	CFS
5. Harvesting costs and productivity	During each harvesting pass in 1999, 2004, and 2009	Logging cost analysis for each treatment	FERIC, DMI
6. Mixedwood regeneration (density/stocking) surveys	As required by LFS acts and regulations	Determine regeneration and stocking status of each block	DMI, LFS
7. Aspen regeneration R&D	1994, 1995, and 1998	Assess effects of shading on soil temperature and aspen suckering and growth in selected treatments, and report results	CFS, DMI
8. Routine wind monitoring on-site and Manning airport towers	Frost-free periods from 1994 to 2014 annually (20 years)	Tower/instrument maintenance, data collection, analysis, and reporting	U of A
9. Wind behavior R&D within treatments	Frost-free periods from 1994 to 1999 annually	Measure and analyze wind behavior in treatment blocks; model wind flow for specified treatment designs and report results	U of A
10. Reports on silvicultural and harvesting treatments	1994 and at 5-year intervals to 2014	Periodic reports of overall project status, complemented by reports in 3, 7, 8, and 9 above	CFS, FERIC
11. Technology transfer	1994 +	Provide both public and technical information transfer of project results using video, writen material, and on-site techniques	CFS

[a] DMI = Diashowa-Marubeni International Ltd.; LFS = Alberta Land and Forest Services; FERIC = Forest Engineering Research Institute of Canada; CFS = Canadian Forestry Service; U of A = Department of Geography, University of Alberta.

harvesting-related understory damage to immature spruce stems, and examined the influence of different levels of operational supervision and special operational techniques. The study results were drawn from trials carried out in central Alberta, between October 1988 and June 1990.

Results of post-harvesting surveys indicate that conventional roadside harvesting equipment (feller-bunchers and grapple skidders) protected more understory than cut-to-length equipment. Understory damage from roadside harvesting equipment decreased as more intensive practices were adopted. Post-harvesting surveys found understory protection levels of 2–16% when no special practices were used, 40–61% with intermediate protection measures, and 52–61% with high protection measures. The cut-to-length equipment left 21–30% of the understory protected when intermediate and high levels of understory protection were incorporated. With roadside harvesting equipment, the amount of understory destroyed decreased significantly when understory protection practices were incorporated into the harvesting operations. Cut-to-length equipment injured more, but destroyed fewer, understory stems than conventional equipment.

The differences achieved in understory protection between using roadside and cut-to-length harvesting equipment were directly related to felling and skidding methods. Roadside harvesting equipment left well-defined skid-trails with islands of relatively undamaged understory between the trails. Cut-to-length equipment left skid-trails that were less visible, but more of the understory between the trails was damaged.

Study results indicated that where roadside harvesting equipment was used harvesting costs increased as the level of understory protection increased. Roadside harvesting costs ranged between \$14.70 and \$14.90/m^3 when the understory was not protected. With intermediate levels of understory protection the range was \$13.90–\$17.40/m^3, and with a high degree of understory protection, \$18.40–\$25.00/m^3.

The cost of harvesting areas with cut-to-length equipment was similar for the sites harvested using either intermediate or high levels of understory protection, \$22.50–\$22.80/m^3.

The special practices used on the treatment blocks increased harvesting costs. Pre-harvest organization remained the same for the Drayton Valley studies, but increased \$0.20/m^3 for the cut-to-length equipment and increased by \$0.70–\$1.70/m^3 for the Hinton and Whitecourt 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 sites. FERIC found that on-site supervision 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 \$0.50–\$1.40/m^3.

Successful protection of immature spruce during aspen harvest can be significantly increased through planning, proper equipment selection, on-site supervision, modified operating techniques, and crew training and motivation.

Silviculture

The silviculture component of Project 1480 addressed post-harvest blowdown of residual spruce on mesic sites. It identified the need for development and application of spruce blowdown risk criteria, particularly for moist-to-wet sites. It also documented post-harvest growth and yield of residual spruce and regeneration of aspen and poplar.

Wind Damage

Pooled blowdown data from six treated blocks in the Whitecourt, Hinton, and Drayton Valley areas showed that wind damage increases with tree height. Trees up to 7 m tall had less than 5% wind damage and those over 10 m had more than 10% wind damage in the first 2 years after aspen harvest, with additional third-year damage to trees over 10 m.

Assessment of wind damage 5 years after harvest showed negligible increase in windthrow in all height classes. The lack of significant damage between 3 and 5 years after harvesting is very important. It suggests that spruce stability has gradually improved with time since harvesting. Such an improvement in tree stability results from crown, stem, and root system growth and is a function of increased light and of wind stimulus after release. The slenderness coefficient (height/dbh ratio) is strongly related to tree stability, and is suggested as a criterion for operational pre-harvest assessments of wind resistance in spruce, particularly when integrated with relevant stand composition, site, and topographic factors. Slenderness coefficient decreased on all treated blocks over the 5 years following aspen harvest. This was particularly significant in taller, more vulnerable trees.

The results of Project 1480 indicate that white spruce, like other coniferous species, can gain considerable stability in as little as 3–5 years after release. This finding is of paramount importance in confirming the assumptions used subsequently in the design of Project 8032 and in developing operational strategies to minimize blowdown damage.

Growth and Yield

There is a critical need for a mixedwood growth and yield methodology that reflects the realities of variable density and stocking of the major species in mixedwood stands. Growth data for Project 1480 covering the period 1989 to 1993, and a suggested yield prediction methodology, are presented in the report.

Data on periodic diameter and height growth of residual white spruce in each of the three study areas (Whitecourt, Hinton, and Drayton Valley) were positive and relatively uniform across the range of post-harvest densities sampled over the 4–5 year post-harvest period.

There was sufficient size differentiation in white spruce understory by age 50 to allow a good selection of up to three relatively free-growing crop trees/plot (equivalent to 264 crop trees/ha) across a range of densities in all three areas. This suggests that post-harvest tending, to maintain crop tree growth, may be unnecessary in such highly clumped immature spruce residuals of this age.

Periodic annual volume increment per hectare increased with residual spruce density for all trees of more than 0.5 m and for a selected sample of the fastest growing 264 crop trees/ha. The pai varied by area, ranging from about 2.5 to 5 m^3/ha/yr for all trees taller than 0.5 m, at residual densities of 800 trees/ha and over.

Yield projections for the white spruce residual and new aspen regeneration in a sample area for the 60-year period following the first harvest in the two-stage model used in this report resulted in an estimated yield of 217 m^3/ha of spruce and 86 m^3/ha of aspen at the second harvest. This is a reversal of the species proportion in the first harvest, when aspen yield was 238 m^3/ha and spruce yield 83 m^3/ha.

Aspen and Poplar Regeneration

In stands treated according to the two-stage harvesting model it is assumed that after aspen canopy removal, aspen regeneration of acceptable quality would develop in openings and form the hardwood yield component of the stand at the second harvest. Therefore the density, stocking, and growth of aspen and balsam poplar after the first cut is of particular interest in yield predictions, as well as in sustaining a mixedwood stand. Successful aspen regeneration is dependent on an adequate density of roots for suckering, increased soil temperature after harvest, and sufficient light for growth after sucker emergence. These prerequisites were largely satisfied by the first harvest on all three areas, which resulted in no area being less than 85% stocked with aspen 4–5 years after harvest. The observed aspen densities satisfy minimum requirements of 6000 suckers/ha after 3 years, confirming assumptions made in the two-stage harvesting and tending model.

Balsam poplar stocking averaged more than 30% and was similar on all three areas by 4–5 years after harvest. Poplar continued to ingress up to 5 years, whereas aspen densities began to decline by the third year. Densities ranged from 500 to 3000/ha after 4–5 years, giving a normal proportion of poplar to aspen on the treatment areas compared to other areas in west-central Alberta.

Balsam poplar regeneration and growth was encouraged by mineral soil disturbance, but aspen regeneration and growth was discouraged. This was attributed in part to parent root damage on landings and skid-trails. This effect should contribute to a greater proportional representation of balsam poplar in future stands with similar logging-related site impacts.

Future growth and development of aspen is expected to diminish over the rotation as canopy space declines in proportion to the density, distribution, and growth of released white spruce residuals.

Project 8032

Project 8032 was the sequel to Project 1480. The main planning thrust was to perpetuate healthy boreal mixedwoods by devising silvicultural strategies and designing harvesting plans that test ways to minimize wind damage to immature spruce residuals on moist to wet sites, and to encourage vigorous deciduous regeneration following harvesting of the aspen overstory. The health and productivity of principal tree species, and their natural regeneration capabilities, were emphasized. Wildlife and watershed concerns were addressed through the relevant FMA ground rules and by consultation with specialists in Alberta Land and Forest Services.

The project was initiated in 1992 on 11 treatment blocks on a 530 ha study area northwest of Manning, Alberta. Pre-harvest silvicultural assessments and ecosite classification preceded treatment allocation and logging layout. The project has a planned 20-year series of harvests and surveys. It also has research and development components on long-term growth and yield and shorter-term aspen regeneration and wind behavior. Silvicultural and harvesting systems were designed to provide varying degrees of wind protection to residual immature spruce following aspen harvest and represented a varying range of harvesting difficulty using conventional feller-buncher/grapple skidder technology.

Silvicultural System Design

Anticipating the need to address high-wind damage risk related to two-stage harvesting and other silvicultural systems in boreal mixedwoods, studies provided an analysis of wind statistics and extreme wind gust probability in Alberta was done, and worldwide literature on wind-risk management was reviewed. This provided the background for planning an array of silvicultural systems with incremental wind protection levels varying from no protection to very high protection.

Designs were based on a directional analysis of annual maximum winds in the project area. This indicated a predominance of extreme winds from the northwest and west requiring a north–south alignment of the longitudinal axes of cutblocks and strips (perpendicular to the wind). Analysis also showed short return periods for extreme winds.

Regression analysis of sampled immature spruce showed a high correlation between slenderness coefficient and both number and volume per hectare of immature spruce, demonstrating that high spruce densities and associated increased side shade lead to increased slenderness coefficients and increased instability.

The combination of three factors—high slenderness coefficient, mean height of 10 m, and windiness of the region (short return period for high winds)—coupled with potential intermittent saturated soil conditions, suggests a high risk rating and danger of extensive windthrow in retained spruce in unprotected cutblocks. Wind protection measures should be intensive and should be given a high priority in the design and selection of suitable silvicultural systems not only for Project 8032 but for similar stands in the region.

Harvesting System Design

Harvesting systems were designed to achieve silvicultural system objectives. The equipment used to harvest all the blocks consisted of a Caterpillar EL300 feller-buncher with a 55.9 cm Koering high-speed saw felling head, a John Deere 648D grapple skidder, and a Lim-mit LM2200 roll-stroke delimber mounted on a Caterpillar DL300B carrier. In addition, a prototype zero tailswing feller-buncher, the Mountain Cat, was demonstrated on a portion of block F-6-1, and a Caterpillar 518 grapple skidder was used to supplement skidding.

Harvesting cost and productivity studies were conducted, with detailed work-sampling studies for each machine, for later analysis and comparison between silvicultural systems tested of harvesting costs and productivity.

The report provides observations on and practical solutions to operational problems that arose during implementation of a wide variety of modified harvesting procedures. These should be useful to forest managers addressing new priorities on alternative silvicultural and harvesting practices.

Preliminary Wind Damage Results, Block F-6-3

Block F-6-3 was chosen to illustrate initial windthrow patterns on one treatment in Project 8032.

Considerable windthrow occurred on block F-6-3, which was cut in 150 m wide strips, soon after harvest in September 1993. Analysis of large-scale color aerial photographs, taken in fall 1993 indicated that, in the sample of 120 windthrown spruce trees on four strips, none were found in the distance 1–20 m from the west edge of the strips. About 10% of damage occurred in the distance 21–70 m from the west edge of the strips. From 70 m on, the incidence of windthrow gradually increased to a peak at about 111–120 m from the west edge. Thereafter, the incidence of damage decreased.

Further assessment of wind damage from spring and fall 1994 photographs should show the difference between levels of protection provided by the different silvicultural systems tested on Project 8032. On-site wind monitoring and planned research into within-block wind behavior should give insight into the principles of wind action in different harvest patterns. This will help extrapolate results from Project 8032 to other areas.

Future

Project 8032 has a 20-year planned harvest and assessment cycle. However, much of the information crucial to assessing and reducing wind damage to residual spruce, as well as to assessing residual spruce growth and yield and aspen regeneration, should be available within the first 5–10 years. Priorities for future research and development and technology transfer are:

- five-year priority on the second harvest pass, wind damage assessment, aspen regeneration and wind behavior research and development, and short-term technology transfer;
- ten-year priority on wind damage assessment, growth, and yield measurements, and longer-term technology transfer; and
- priorities for project continuation beyond 10 years should be set with reference to the relevance of 5 and 10 year results to forest management priorities at that time; because of their long-term nature, growth and yield measurements in particular may merit priority beyond 10 years.

ACKNOWLEDGMENTS

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APPENDIX 1
ENLARGED MAP OF PROJECT 8032 AREA

Map is located in back pocket of publication.

APPENDIX 2
PRE- AND POST-HARVEST MEASUREMENT PROTOCOLS

a) Measure all trees >1.3 m in height, tagging conifer only (black spruce-wet areas will not be tallied).

b) Record all the following for coniferous species, and dbh and height only for deciduous.

Block: see Table 1
Transect no.:
Date: year, month, day
Segment and strip:
Ecosite:
Species: Sw, Sb, Aw, Fb, Pl, Bw, Pb, and Lt
Tree no: 1 to 10 000
X distance: 1 to 10 000 m
Y distance: 0 to 2.5 m
Y direction: N or S
Dbh: 0 to 100 cm to nearest 0.1 cm
Height: 0 to 30 m to nearest 0.1 m-sufficient for H/D curves
Age: Bh to nearest year for the range of spruce heights
Ht. to live crown: nearest 0.1 m

c) Damage condition and distribution codes:

00 Undamaged
11 Acceptable logging damage
Broken or lost leader
Broken branches
Cambium scrape
12 Acceptable natural damage
Broken leader
Broken branches
Whip
14 Unacceptable natural damage
Broken stem
15 Unacceptable logging damage
Broken stem
Gouge/hurt
Pulled out
16 Unacceptable natural lean
17 Unacceptable logging lean
40 Insect damage
41 Disease
77 Frost damage
95 Standing dead
98 Blowdown—not logged
99 Harvest/missing

L M H Vigor
RX—RY Roads-in block
SX—SY Seismic line
UX—UY Uncut

LX—LY Landing
MX—Y Machine corridor
BX—BY Buffer
AX—AY Amoco road

APPENDIX 3
PROTOCOL FOR ASSESSMENT OF TREE MORPHOLOGY OF WHITE SPRUCE UNDERSTORY

Project: #8032 Harvesting options to favor immature white spruce and aspen regeneration in boreal mixedwood, Peace River–Manning

#8033 Wind risk criteria of released white spruce understory

Sampling intensity: 50 trees per stand (greater than 10% of the sampled trees on the transect lines)

Location of trees: 25 on the transect strips
25 destructively sampled, adjacent to the transect strips

Selection of trees: Select 2–3 transect lines that represent the stand/block, e.g., #5, #3, #2 in F-1-1. The sum of the transect lines' distances divided by 50 trees establishes a sampling interval: e.g., 1500 m:50 = 30 m.

Bypass areas: Within 15 m of creek, beaver dams, stand edges, distinct depressions with high water table and *Carex,* and stand openings of tree height radius.
Using the transect printouts, select a sample tree closest to the 30 m mark, and write in the tree number.
Every second tree will be outside the transect strip and will be destructively sampled for stem analysis.

Exclude trees: With recognizable damage (i.e., bark peeling, browsing, whipping)
In clusters or pairs closer than 0.5 m
Trees ≥26 cm dbh

In-strip trees: Record tree number.
Measure dbh, bd, height, 1992 height increment, crown length.
Crown width at 0, ¼, ½, ¾ of the crown length on east and west sides.
Photograph the tree.
Estimate crown density by quarters of tree crown.
Determine canopy density in four cardinal directions using a canopy densiometer.
Stand with your back to the tree so that, after leveling the densiometer, the crown edge touches the bottom line of the square grid.

Stem analysis trees: Record the number of the nearest tree, measure dbh, bd.
Estimate crown/foliage density in each quarter of the crown.
Photograph the tree.
Fell tree in south or north direction.
Measure: Total height and crown length.
1992 height increment, 1991 height increment.
Length of lateral shoots in the last (1992) whorl.
Length of 1991 and 1992 lateral increments in the whorl second from the top.
At 0, ¼, ½, ¾ of the crown length locate the nearest whorl and determine:
Total branch length.
1992 lateral increment.
Count of whorls from the top (at least for the ¾ and ½ crown locations).
All measurements disregard current (1993) growth.
All lateral measurements are on both east and west sides of the crown.
Cut disks, 0, 0.3, 0.5, 1.3, 2, 3, 4, 5 m etc. if the total height is ≤10 m.

For taller trees, cut disks at 0, 0.3, 0.5, 1.3, 2, 4, 6, 8, 10 m, etc.
Stand on the stump and determine canopy opening using a spherical densiometer in four cardinal directions.
Using the stump as a plot center, measure dbh by species, distance, and azimuth of all trees up to 6 m.
Disregard trees less than half the height of the sampled trees unless they are in the first 2 m.
If any large conifer tree is beyond this distance, make note of its cardinal direction and estimated distance.

Aspen trees in the parent stand: In each location of a stem analysis tree, locate one aspen nearest to the stem analysis tree.
Measure: Dbh, height, and maximum crown diameter in two directions.
Out of these 25 aspen trees select 10 trees per stand and cut disks for stem analysis at 0, 1.3,5, 10, 15, 20, 25 m. The main selection criterion is soundness, lack of rot.

TREE MORPHOLOGY OF WHITE SPRUCE STEM ANALYSIS TREES

The nearest tree #: **Transect:**

Dbh: **Bd:** Crown/foliage density
0–¼: ¼–¾: ¾–top

Total height: 92 Ht. Incr.:
92 Lat. Incr.: East:
West:

Crown length:
Whorl count (crown from the top):

0 :	Branch Length	East:	92 Incr.	East:
		West:		West:
¼ :	Branch Length	East:	92 Incr.	East:
		West:		West:
½ :	Branch Length	East:	92 Incr.	East:
		West:		West:
¾ :	Branch Length	East:	92 Incr.	East:
		West:		West:

Canopy density:	N:	E:	S:	W:
Adjacent trees:	Dist:	Azim:	Dbh:	Species:
Aspen:	Dbh:	Height:	Crown dia:	