

Montane Alternative Silvicultural Systems (MASS)

Proceedings of a Workshop
held June 7-8, 1995
in Courtenay, British Columbia



CANADA-BRITISH COLUMBIA PARTNERSHIP AGREEMENT ON FOREST RESOURCE DEVELOPMENT: FRDA II

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held June 7–8, 1995
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Edited by:

J.T. Arnott¹, W.J. Beese², A.K. Mitchell¹ and J. Peterson¹

¹ Pacific Forestry Centre, Canadian Forest Service, Victoria, B.C.

² Sustainable Forestry Division, MacMillan Bloedel Ltd., Nanaimo, B.C.

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For additional copies and/or further information about the Canada-British Columbia
Partnership Agreement on Forest Resource Development: FRDA II, contact:

Canadian Forest Service
Pacific Forestry Centre
506 West Burnside Road
Victoria, B.C. V8Z 1M5
(604) 363-0600

or B.C. Ministry of Forests
Research Branch
31 Bastion Square
Victoria, B.C. V8W 3E7
(604) 387-6721

Foreword

The cooperative Montane Alternative Silvicultural Systems (MASS) research project addresses regeneration, wildlife habitat, and aesthetic concerns in managing forests at higher elevations on Vancouver Island. A series of integrated studies are examining the biological and economic consequences of alternative silvicultural systems. The costs and feasibility of harvesting these old growth forests using small Patch Cuts, Green Tree Retention and Shelterwood systems are being documented. Many long-term studies will evaluate the impacts on forest dynamics, soils, microclimate and biological diversity.

The objective of this workshop, held from June 7–8, 1995 in Courtenay, B.C., was to provide a forum in which the MASS project's initial findings were presented. Fourteen papers from all members of the research team were delivered to an audience of 100 participants from industry, government and academia, primarily from the Vancouver Forest Region. A field trip was also made to the MASS project site, located 20 km southwest of Campbell River in the Menzies Bay Division of MacMillan Bloedel Limited.

Jim Arnott and Bill Beese
MASS Project Coordinators
July 1, 1995

Acknowledgements

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The Montane Alternative Silvicultural Systems Project: A Research and Operations Partnership

*Roger J. Whitehead
Canadian Forest Service
Pacific Forestry Centre
506 West Burnside Road
Victoria, B.C. V8Z 1M5*

Coastal British Columbia has some of the world's most productive forested land. The temperate rainforest, and activities of those of us who make our living in it, have drawn this area to the attention of the world. Much has focussed on majestic stands at low elevation, but not all our forest, nor all of its value, is found there. Even our mid- to high-elevation "montane" sites support large volumes of high value timber. Age, species, and structural diversity of these forests provide habitat for many organisms. Because of their position on the landscape, these forests provide the backdrop to spectacular views and are important upslope components of our watersheds with all their associated values. Here, on Vancouver Island, nearly a third of our total land area is "montane forest." Two-thirds of this has had no recent disturbance; most fits the definition of "old-growth" forest.

As more and more people settle on, or visit, Vancouver Island, the demands on our forests both increase and diversify. Since timber operations began to move upslope thirty years ago, montane forest types have become an increasingly important source of fibre for industry and employment for island communities. That move upslope presented a regeneration challenge that required changes in operational practice. The same approaches used successfully at low elevation did not always work. New approaches, based on better understanding of the ecology of montane sites, developed from cooperation between scientists, foresters, and field staff, focussed the efforts of several agencies and several disciplines on problem solving and adaptive management.

Shifts in population and changing global and local attitudes, present overwhelming pressure to change operational practice again. This expectation of change is captured in the recent recommendations of the Scientific Panel for Sustainable Forest Practices in Clayoquot Sound, which provide a new entry to the forestry jargon: "variable-retention silvicultural system." If only we could say: "No sooner said than done" with confidence, but many questions remain unanswered about the safety, economic viability and environmental sustainability of management systems based on non-clearcut harvest. Once again, the key to finding workable solutions will be close cooperation between the research and operational communities through a process of adaptive management. The Montane Alternative Silvicultural Systems (MASS) partnership has begun this process.

Partnerships such as the MASS run on two principal fuels: people and money. You will see the names of many of the key people attached to the presentations in these proceedings, but there are others that should be acknowledged: Terry Rollerson for calling the first *ad hoc* meetings to discuss how to tackle silvicultural systems research on the South Coast in 1989; Janna Kumi, for her singular devotion to developing the vision of MASS; Ted Kimoto, Ken Buxton, Marv Clark, and Bob Dobbs for marshalling some of the best human resources of MacMillan Bloedel, the Canadian

Forest Service and FERIC; John Drew, Elaine Teske, Henry Benskin, and Dale Draper for their faith that this ambitious project was worth supporting with public money. These partnerships do require money. The MASS project has been generously supported by the Canada–B.C. Partnership Agreement on Forest Resource Development – “FRDA II,” by the Forestry Practices Initiative of Canada’s Green Plan, and by the core budgets of the Canadian Forest Service, the Forest Engineering Research Institute of Canada, and MacMillan Bloedel Ltd. The MASS project has made a difference already. More than 500 forest workers toured the site during or soon after the logging operation and carried back new understanding to their own operations. The project has attracted visitors from around the world, has featured prominently in discussions of Canada’s Parliamentary Committee on Clearcutting and the Clayoquot Scientific Panel. In these proceedings, you will find the first results of scientific studies that will continue to provide baseline information for decades to come.

Montane Alternative Silvicultural Systems (MASS)

Introduction and Objectives

William J. Beese
Forest Ecologist
MacMillan Bloedel Limited
65 Front Street
Nanaimo, B.C. V9R 5H9

Abstract

The cooperative Montane Alternative Silvicultural Systems (MASS) research project addresses regeneration, wildlife habitat, and aesthetic concerns over clearcutting at higher elevations on Vancouver Island. Integrated studies are examining the biological and economic consequences of alternative silvicultural systems. The cost and feasibility of harvesting old growth using small Patch Cuts, Green Tree Retention and Shelterwood systems were documented. Long-term studies will evaluate the impacts on forest dynamics, soils, microclimate and biological diversity.

Project Rationale

Concerns over high elevation regeneration performance in large clearcuts was the primary reason for establishing the Montane Alternative Silvicultural Systems (MASS) study. Coastal "montane" forests have a winter snowpack and are found between 700 and 1100 metres in elevation on Vancouver Island. Observations suggest that on some clearcuts at these elevations, regeneration of natural and planted trees may not be meeting current growth expectations because of patchy stocking or growth inconsistencies (Koppelaar and Mitchell 1992). The apparent growth problems may be related to environmental conditions on large clearcuts that create unfavorable microclimate, vegetation competition, nutrient availability or alterations to ecosystem processes affecting forest regeneration. There is little data on ecosystem processes in montane and subalpine forests on which to base silvicultural decisions. These predominantly old-growth forests represent about 30% of the land base on Vancouver Island. For MacMillan Bloedel, 25% of its future Allowable Annual Cut is dependent upon this resource. Silvicultural systems that provide for canopy protection to reduce microclimatic extremes may help regenerate the shade tolerant amabilis fir (*Abies amabilis*) and western hemlock (*Tsuga heterophylla*) that dominate these forests.

At the same time, greater regard for multiple forest values including wildlife habitat, biological diversity and visual aesthetics is prompting foresters to consider new approaches for managing coastal forests. There is growing public pressure on industry and government to reduce the size and extent of clearcutting in B.C. On the coast, there is very little experience with other silvicultural systems. Forest managers need to know where alternatives to clearcutting are feasible, economical and ecologically sound. This study provides an opportunity to address a variety of today's challenges.

The MASS cooperative is a multi-agency research effort between MacMillan Bloedel, the Canadian Forest Service, the Forest Engineering Research Institute of Canada (FERIC), the University of British Columbia and the University of Victoria.

Objectives

The objectives of the MASS study are to:

1. Test alternative silvicultural systems for montane coastal B.C. forests;
2. Document the operational costs and feasibility;
3. Study the biological and silvicultural impacts.

A multi-disciplinary team is studying harvesting feasibility and economics, growth and yield, microclimate, soil disturbance and nutrients, forest floor decomposition, natural and planted regeneration, forest bird diversity, vegetation succession, seedling response to competition and nutrition, and forest health. Results of these studies will be used to develop guidelines for selecting silvicultural systems, species and management options for montane ecosystems to meet regeneration, aesthetic and wildlife objectives, without compromising worker safety.

Study Area

The study is located on MacMillan Bloedel's private land south of Campbell River, B.C. within the Montane Moist Maritime Coastal Western Hemlock biogeoclimatic variant (CWHmm2) (Green and Klinka 1994). The study area ranges in elevation from 740 to 850 metres on a northerly aspect. Slopes are generally less than 20%.

The old-growth forest on the study area was dominated by western hemlock and amabilis fir, with varying amounts of western redcedar (*Thuja plicata*) and yellow-cedar (*Chamaecyparis nootkatensis*). Overstory trees ranged in age from 200 to 800 years. Tree ages, stand structure and the presence of charcoal at the mineral soil surface 10 to 40 cm under the forest floor suggest that the stand developed in the absence of fire disturbance or large-scale windthrow for at least 500 years, and probably much longer.

"HwBa-Pipecleaner moss" is the dominant site association on the study area. It occurs on well- to moderately well-drained slopes characterized as a "fresh" soil moisture regime. Alaska and oval-leaved blueberry dominate the shrub cover. The moist to very moist "BaCw-Salmonberry" site association occurs in depressions and seepage tracks, most often intermixed with the Pipecleaner moss association in a complex mosaic. Devil's club forms dense shrub cover in portions of this association. Minor amounts of the wet "CwSs-Skunk cabbage" site association are also present, mostly in small depressions.

Soils within the study area are predominantly Orthic and Gleyed Ferro-Humic Podzols. They are generally over one metre deep, but some areas have shallow soil over sandstone, shale or conglomerate bedrock. Well-drained to moderately well-drained soils occur on middle to upper slopes and hummocks. Moderately well-drained to imperfectly drained soils occur on lower slopes and in depressions. Many portions of the study area have a mosaic of well-drained and imperfectly drained soils in response to the hummocky topography. Soil conditions vary widely over short distances. Bogs have developed where a few pockets of poorly drained soils occur. Soils in the study area have high clay content (20 to 48 percent) in relation to typical Vancouver Island soils. Surface organic horizons (i.e., forest floor) are dominated by Mor humus forms (Humimors and Hemihumimors). The typical sequence of horizons is a thin (0.5 to 1.5 cm) litter layer, a 3 to 5 cm matted "F" layer, and a well decomposed humus layer of variable thickness. Decomposed wood is a predominant component of deeper humus layers.

Experimental Design

The experiment includes three replicates each of silvicultural systems representing a range of overstory removal: a uniform shelterwood, and two variations of clearcutting—small Patch Cuts, and Green Tree Retention. Adjacent to these treatments is a 69 ha clearcut and an old-growth baseline monitoring reserve (Figure 1). Individual tree and group selection systems were considered, but were not deemed feasible for the stand conditions and equipment available.

Each replicate occupies an area ranging from 8.6 to 11.5 hectares. Most replicates were rectangular, approximately 250 m × 360 m. The three replicates of each of the three clearcut-alternative systems occupies an area of 94 hectares. Treatments were allocated to this area by dividing it into nine roughly equal blocks and three groups of three (west to east). Treatments were assigned randomly within each group. The group assignment ensured distribution of each treatment across the site. Because the intent of the Green Tree Retention treatment is to represent a small clearcut with residuals, a constraint was placed on random assignment to reject the occurrence of two adjacent Green Tree replicates.

The large Clearcut to which the alternatives will be compared was harvested during 1992 (58.5 ha) and 1993 (10.6 ha). The untreated old-growth “control” (20 ha) will remain between the conventional clearcut and alternative systems for a minimum of 20 years. The Clearcut treatment was assigned to a large neighboring clearcut rather than 9-hectare clearcuts interspersed within the other treatments in order to be representative of current and past practices. The old-growth control was also assigned to a single larger area, rather than three 9-hectare blocks, to minimize edge effects. Old-growth buffers to the north and south of the alternative systems block will remain for wind protection for the foreseeable future. Other areas surrounding the treatment blocks could be harvested any time in the future, though there are no immediate plans for development.

Experiments influenced by edge effects were located within a 1.6 ha “core” in the centre of each 9 ha treatment block. The treated buffer surrounding the core was defined as two to three tree lengths (85 m) from the block boundaries. All studies were referenced to a 60 m sampling grid with permanent metal markers established before harvesting. Forest cover and plant associations were mapped at 1:5000 scale before harvesting. Forest inventory was done at about three times the normal intensity for a commercial timber cruise, and included measurement of several additional stand attributes, such as coarse woody debris and advance regeneration. Pre-harvest monitoring to characterize the old-growth forest also included physical and chemical soil properties, above- and below-ground microclimate, vegetation cover, and breeding bird communities.

Silvicultural Systems

The treatments represent a gradient of microclimatic conditions and residual forest cover for regeneration protection and wildlife habitat. Each was designed with specific objectives in mind.

Clearcut

A 69 hectare area was harvested over a two-year period with two adjacent clearcuts to provide an example of clearcutting practices for comparison to alternative systems. The regeneration objective is to establish a mixed stand of conifers through natural regeneration from advanced stocking and seed-in, supplemented by fill-planting to achieve stocking targets and desired species composition.

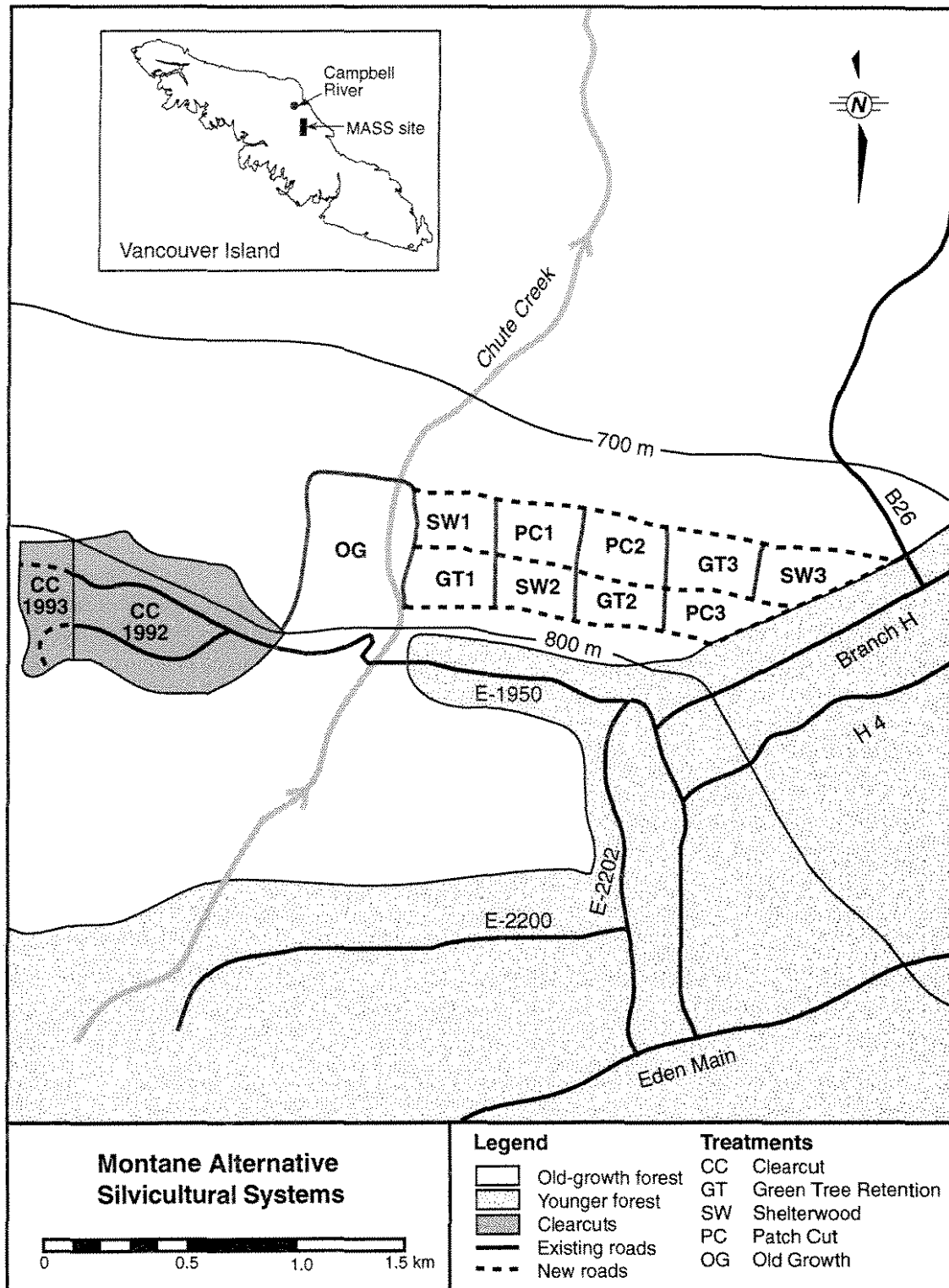


Figure 1. Study area location and layout.

Patch Cut

Small cutblocks were designed with alternating leave strips so that regeneration is within two tree lengths of an edge. This provides seed-fall and protects regeneration against snow, wind and temperature extremes. All trees were cut in three 1.5 to 2 ha patches (approximately 120 × 125 m) within each treatment block. Except for size, the concept is similar to a strip shelterwood. The remaining 50 percent of the stand will be harvested after regeneration reaches 10 m in height. This also spreads harvesting over a longer time period for aesthetic and wildlife habitat values. Regeneration will be achieved primarily through natural stocking, supplemented by planting as required.

Green Tree Retention

The goal of this treatment—also known as clearcutting with reserves—was to leave 25 trees per hectare in small clearcuts to enhance the structural diversity of future stands for wildlife and aesthetics. The appearance is similar to a seed tree system, except that reserves are left for the entire rotation to meet other objectives. Trees were selected for relatively uniform distribution, windfirmness, safety and representation of the entire stand profile. Five snags per hectare will be created in future for cavity nesting birds. Natural regeneration is prescribed, supplemented by planting as required to achieve a mixed species composition.

Shelterwood

This system provides protection for regeneration against snow, wind and temperature extremes, and enhances the structural diversity of future stands for wildlife and aesthetic values. Trees representing the entire stand profile and 30% of the basal area (approximately 200 stems per hectare over 17.5 cm DBH) were left throughout the stand. Reserve trees were selected for yarding feasibility, safety, windfirmness and residual stand structure. Although the approach is considered a uniform shelterwood, clumped distribution was necessary to facilitate harvesting and to protect smaller trees. If feasible and economical, a portion of the leave trees will be recovered when regeneration is established, leaving up to 25 wildlife trees per hectare. A second option identified in the stand prescription is to leave all residual trees for the entire rotation, creating a multi-aged “irregular” shelterwood. Regeneration will be achieved primarily through advanced natural stocking and seed-in.

Harvesting

Roads were built in 1992, and harvesting was completed between May and November of 1993. The Workers' Compensation Board was involved during harvest planning to ensure safety requirements were met. Trees were marked to meet the specific silvicultural objectives established for each treatment. Several days of training occurred, with field input on marking from equipment operators, fallers, researchers and other operational personnel. Manual felling was used in all treatments. Where a marked tree could not be retained, fallers could choose an alternative tree of similar size. Trees were bucked to specified log lengths at the stump to maximize value recovery.

A hydraulic log loader was used to forward or swing the logs from stump to roadside. Hoe-forwarding is the method of choice for yarding timber on gentle slopes. Although this type of logging system has been employed in partial cut treatments of second growth stands, it had not been used before for partial cutting old-growth forests in coastal B.C. In the Shelterwood, access corridors up to 20 metres wide were placed perpendicular to main roads at a maximum spacing of 120 metres. Trees were felled and removed from corridors before felling trees toward them from the surrounding stand. Ground skidding was used in conjunction with hoe-forwarding in the Shelterwood to yard wood from corridors to the main roads.

Application

Much experience was gained from the MASS study that will benefit future application of the systems tested. The study area has already served as an important demonstration area for others planning to implement alternative systems in coastal B.C. Crew involvement in the planning stage was a key element in successful implementation. Close on-site supervision was essential to ensure proper scheduling of harvesting phases for the multiple blocks.

Shelterwood, Green Tree Retention and Patch Cut treatments can be done successfully in old-growth forests under the conditions tested at MASS, but the biological and economic implications will determine whether or not these treatments should be applied elsewhere. Harvesting feasibility and cost results are not applicable to areas of steeper terrain that require different yarding systems.

This project has created a long-term research installation where multi-disciplinary projects can be undertaken in montane coastal forests with replicated alternative silvicultural treatments. The study area has already attracted several additional studies.¹ The experimental installation will be monitored for at least 20 years, at intervals determined by future funding arrangements among cooperators. Ideally, the project will extend to the entire forest rotation.

Project results will assist development of guidelines for forest practices in montane coastal B.C. forests. Challenges to those designing silvicultural systems to meet a variety of management goals include: ensuring that regeneration, tending and product objectives are met; balancing logistics, minimizing windthrow and protecting regeneration during multiple entries; meeting wildlife needs without compromising forest health; and thinking beyond the traditional definitions of silvicultural systems to create innovative approaches.

Acknowledgments

This project was sponsored by the Federal and Provincial governments under the Canada-B.C. Forest Resource Development Agreement (FRDA II). Funding was also provided by MacMillan Bloedel Limited, the Canadian Forest Service, the Forest Engineering Research Institute of Canada and Industry Canada.

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¹ This Workshop Proceedings presents initial findings from the research studies established in the original study plan; Beese, W.J. 1992. Montane alternative silvicultural systems working plan. Woodlands Services Div., MacMillan Bloedel Ltd., Nanaimo, B.C.

Harvesting Logistics and Costs

*Eric J. Phillips, A.Sc.T.
Forest Engineering Research Institute of Canada
2601 East Mall, UBC
Vancouver, B.C. V6T 1Z4*

Introduction

The Montane Alternative Silvicultural Systems (MASS) study is a multi-disciplinary, multi-agency project initiated for both silvicultural and social reasons. The study is a cooperative research project between MacMillan Bloedel Limited (MB), the Canadian Forest Service (CFS), and the Forest Engineering Research Institute of Canada (FERIC), with participation by University of Victoria (UVic) and the University of British Columbia (UBC). The study compared uniform Shelterwood, Green Tree Retention, Patch Cut and Clearcut treatments harvested by the handfelling/excavator forwarding (Figures 1 and 2) technique.



Figure 1. Handfelling.



Figure 2. Excavator forwarding.

This paper presents a summary of the harvesting logistics and a draft summary of the cost portion of FERIC's work. The additional FERIC studies of site disturbance, detailed timing, soil compaction, slash loading and detailed costing assumptions are contained in a separate FRDA report.¹

Felling

All blocks were mark to leave. However, the fallers could substitute a tree of similar size if the marked tree was damaged or if a marked tree had to be felled because of safety. The primary concern in all treatments was the safety of the fallers. Because of the residual trees, and the close proximity of the unfelled stand in the Patch Cuts, the customary practice of maintaining visual contact between fallers was not possible. Typically, only one faller would work in each Patch Cut with one or more fallers working in each Green Tree and Shelterwood unit. The fallers used radios

¹ Phillips, E.J. (in prep). Productivity and cost of harvesting under alternative silvicultural systems. For. Eng. Res. Inst. Can., Vancouver, B.C. Special Rep. Can. For. Serv. and B.C. Min. For., Victoria, B.C. FRDA Rep.

with collar microphones and in some cases earmuff speakers to regularly check with their partner in compliance with WCB check-in requirements. When falling into standing timber and residual trees, branches and broken wood can hang up in the trees, presenting a serious safety hazard. The fallers compared falling the Shelterwood treatment with opening road right-of-way. One lost time falling accident did occur in a Shelterwood treatment.

Although falling in the Shelterwood was the most challenging, the variation in tree size, tree lean and decay made all treatments difficult. In the Green Tree treatment, prescribed small residual trees were very easily knocked over by the tops or even the limbs of large trees and ensuring their retention was difficult. In the Patch Cut treatment the major problem was opening and maintaining a workable face in a relatively small (1.5 ha) opening, given the inconsistent lean of the trees.

Table 1 and Figure 3 present the summary of falling time, cost and productivity by treatment. The productive hours plus prorated delays are used for costing. Delays not specific to the treatment were prorated to all the treatments, while delays relating to research activities and management were excluded from costing. The prorated delays include call out time (allowance for days when it is too windy to fall); on-site safety meetings; faller training; accident reviews; moving time; and light duty. The falling costs for the MASS treatments were from 2% less to 16% greater than for the Clearcut control. The Green Tree treatment had a 2% lower cost than the Clearcut and the other two treatments where from 15 to 16% higher than the clearcut control. The results show considerable variation between replicates (Figure 4) due to differences in severity of and direction of tree lean, number and size of obstacles, steepness and evenness of terrain, and number of snags.

Table 1. Summary of cost and productivity

	Shelterwood	Green Tree	Patch Cut	Clearcut
Area (ha)	27.5	27.3	17.1	69.1
Volume (m ³)	14503	18425	11175	45360
Piece size (m ³)	1.25	1.12	1.12	1.15
Falling				
Time ^a (h)	1069	1138	807	2868
Productivity (m ³ /h)	13.6	16.2	13.8	15.8
Cost (\$/h)	59.14	59.14	59.14	59.14
Cost (\$/m ³)	4.35	3.65	4.29	3.74
Forwarding				
Time ^b (h)	646	569	292	1001
Productivity (m ³ /h)	22.4	32.4	38.3	45.3
Cost (\$/h)	125.00	136.58	137.40	156.20
Cost (\$/m ³)	5.57	4.22	3.59	3.45
Cost at roadside (\$/m ³)	9.92	7.87	7.88	7.19

^a Including prorated delays.

^b Including prorated delays, all machines.

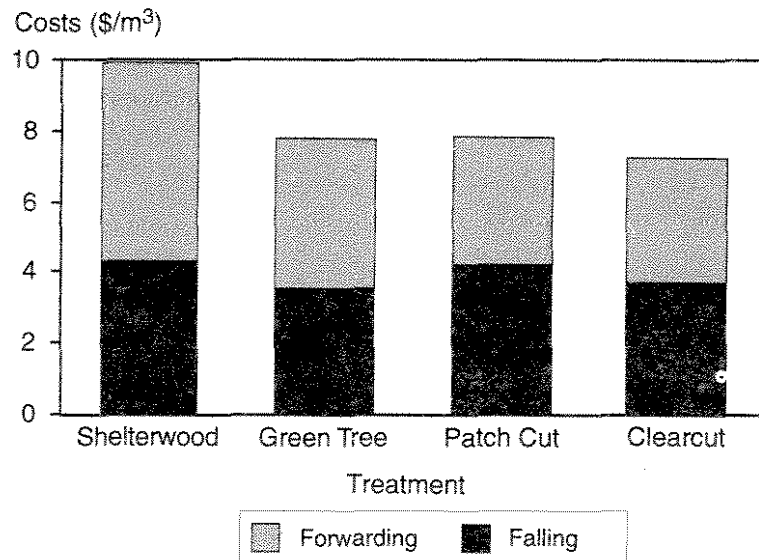


Figure 3. Falling and forwarding costs.

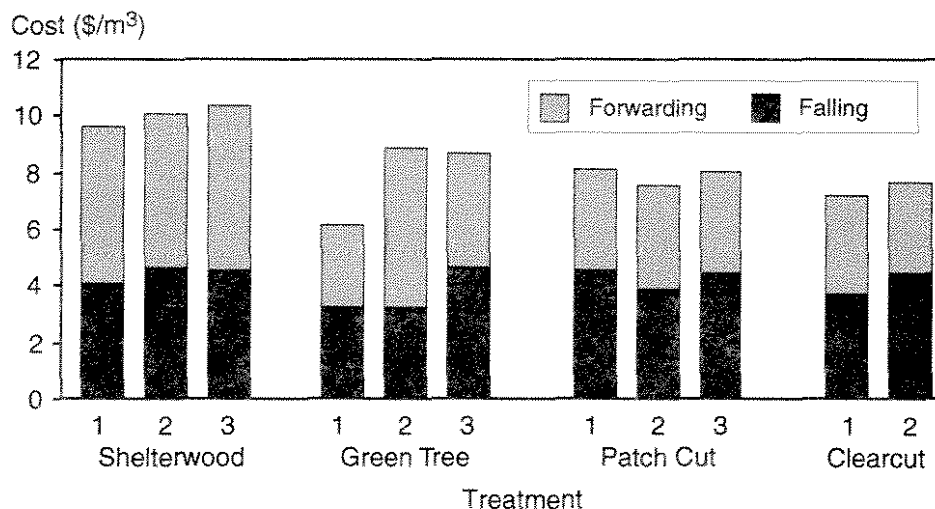


Figure 4. Falling and forwarding costs by replicate.

In all treatments breakage was a problem and is not included in the analysis. To reduce breakage in the Shelterwood, some of the clear-felled forwarding corridors were forwarded several times during falling. As well, log lengths were reduced to a maximum of 16.5 metres.

Forwarding

A project requirement was to utilize existing company equipment wherever possible. Ground-based equipment, excavator forwarding to roadside or excavator forwarding to within super-snorkel reach, is normally used in this terrain. Although a cable system (grapple yarder) was considered for the Shelterwood treatment, deflection was insufficient on some of the yarding corridors. In addition, the logistical problems of coordinating excavator forwarding and grapple yarding within a single block was impractical for this trial. Five forwarding machines were used in the study area. A Thunderbird 1146 (Excavator 1) equipped for excavator forwarding, was the primary forwarder in

all treatments. A Cypress 1825C (Excavator 2) and a Chapman 1825 (Excavator 3) were used for forwarding and loading. A KMC 2500 AG track grapple/line skidder was used in the Shelterwood treatment to forward excavator-decked wood to roadside and was also used to a limited extent in some of the other treatments for forwarding and clean-up. The track skidder was leased for the project to ensure all treatments were harvested in a single season. The super-snorkel was only used in the first Clearcut block.

Excavator 1 used a “serpentine” yarding pattern (Figure 5) in all treatments except for the Shelterwood units. In this pattern, the excavator walks to the timber face or split line that is furthest from and parallel to the road. Forwarding begins by walking the excavator in a path parallel to the haul road and decking all logs at right angles to the haul road. At the end of the block, the excavator turns to a new path parallel to the first and decks all new logs and then swings the previous log deck to the new deck. In theory, each pass with the excavator will move the log deck 50+ metres closer to the road. This pass distance is the sum of twice the excavator reach (14.6 metres) plus slightly less than twice the log length (17 metres). However, in Clearcut 1 the actual forwarding distance was 29 metres while in the Patch Cuts and Green Tree units it was 27 and 23 metres respectively. The limitations were primarily due to terrain—swampy pockets and large stumps—and the variability of log size with the large logs being beyond the lifting capacity of the excavator at full extension and the small short logs not being capable of long forwarding distance.

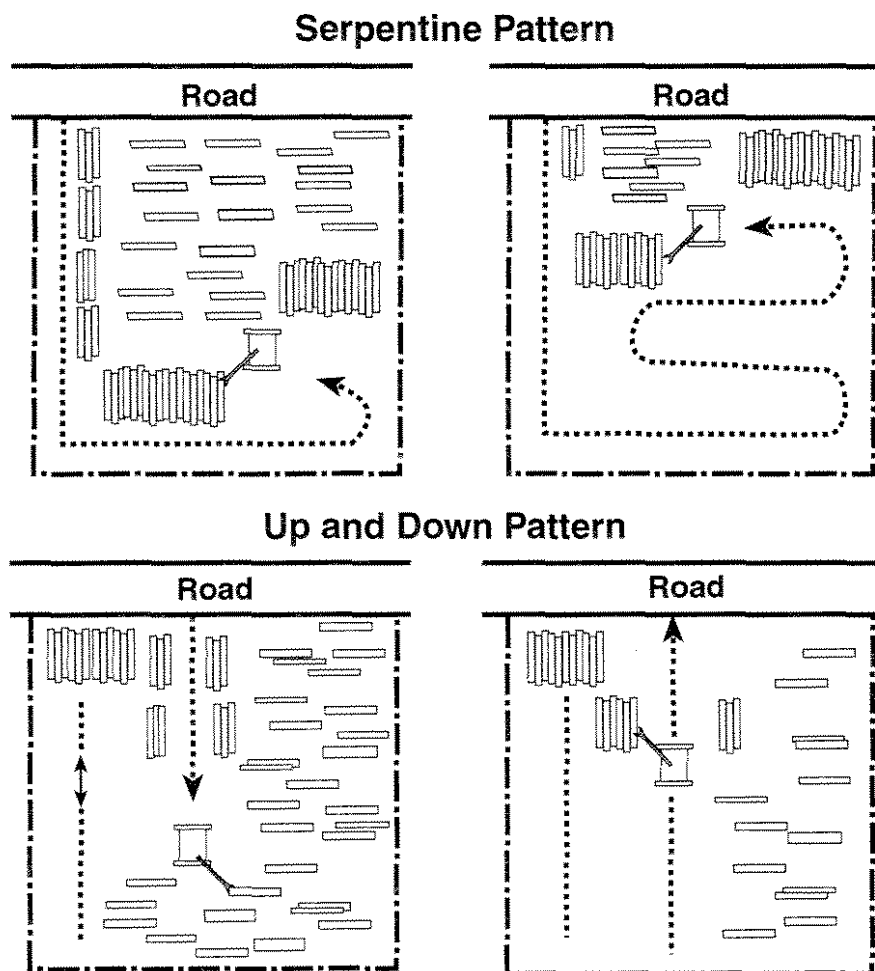


Figure 5. Forwarding patterns.

In the Shelterwood treatment, Excavator 1 used a different forwarding pattern which was a modification of the “up and down” method. The excavator walked from the clear-felled forwarding corridor, between the standing trees and piled the logs within reach until it had advanced to the split line between forwarding corridors. The excavator then reversed and forwarded the piles to the corridor for forwarding to roadside by the track skidder.

Excavators 2 and 3 used the serpentine pattern in the Green Tree blocks and the Patch Cut, and the up and down pattern in Clearcut 2 and the Shelterwood.

The track skidder worked primarily in the Shelterwood units with some work in one Green Tree unit. In the Shelterwood units, the tracked skidder forwarded the logs, decked by the excavator on the corridors to roadside. In the Green Tree unit, the skidder forwarded logs, skidding from the stump to roadside with some orienting by Excavator 1, of log butts, to facilitate grappling. The track skidder also acted as a clean-up machine by retrieving logs missed by the excavator.

The costing is calculated using FERIC’s standard methods. Overall the least costly forwarding was the Clearcut treatment at \$3.45/m³ followed by the Patch Cut at \$3.59/m³, the Green Tree at \$4.22/m³ and the Shelterwood at \$5.57/m³ (Table 1). Using the Clearcut cost as a base, the Patch Cut cost was 4% higher, the Green Tree was 22% higher and the Shelterwood was 61% higher. The three replicates with the lowest forwarding costs were Green Tree 1 at \$2.86/m³, Clearcut 2 at \$3.22/m³, Patch Cut 3 and Clearcut 1 at \$3.49/m³ (Figure 4). Either there is no relationship between the falling cost and the forwarding cost, or the differences were overshadowed by another factor. (It had been theorized that a higher falling cost may result from more careful orientation of logs for forwarding and therefore result in a lower forwarding cost.) The lowest forwarding cost was in replicates with Excavator 1 as the primary machine. Excavator 1 was the newest machine, had the operator with the most experience in excavator forwarding and was the machine with the most suitable specifications. For excavator forwarding, the most important machine specifications are high ground clearance, long boom reach and adequate power.

The combined falling and forwarding costs were 10% higher for the Patch Cut and Green Tree and 38% higher for the Shelterwood than the Clearcut base.

Much of the success of this trial is related to the project planning and coordination. The crew was informed of and accepted the rationale of the objectives and in most cases accepted the challenge and tried to find solutions to operational problems. Throughout the study, the researchers communicated with the crew and answered questions as they arose.

Several factors other than harvesting cost affect the success of these silvicultural systems. The costs here do not include the value of the timber left behind, tree marking and additional supervision. Regeneration success and long term windfirmness are also critical issues.

What did we learn?

- The treatments are possible with conventional equipment in this terrain.
- Short log lengths, and hotter logging can reduce damage.
- The most effective yarding was with a purpose-modified excavator.
- The harvesting costs were about 10% greater for the Patch Cut and Green Tree treatments and 38% greater for the Shelterwood compared to the Clearcut base cost.
- The significance of the cost difference will depend on the effect of the treatments on regeneration performance and if the stands remain windfirm.

Growth and Yield in Montane Forests

*N. Smith
MacMillan Bloedel Ltd.
65 Front St.
Nanaimo, B.C. V9R 5H9*

Introduction

Montane forests comprise about 30% of the landbase on Vancouver Island. Much of this area occurs in the CWHvm2 biogeoclimatic unit which is generally found above 600 m and below 900 m elevation; the remainder being comprised of the CWHmm2 and MHmm1 biogeoclimatic units, extending from 700 to 1200 m, though the CWHmm2 unit can extend to lower elevations (350 m+) on cold air drainage sites. Most of the concern over regeneration performance and growth and yield seems directed at the higher elevations within these variants. Neither the exact extent of, nor the nature of the concern, is explicitly defined however.

The purpose of this paper is three-fold: 1) review of the growth and yield work at the MASS site, 2) examination of MacMillan Bloedel's Permanent Sample Plots (PSPs) in amabilis fir in the above variants and 3) provide a brief overview of some regeneration concerns.

Mass Site

Pre-treatment PSPs were established in October, 1992. Post-treatment plots were assessed November 1993. Plot dimensions comprised 80 m × 80 m in the Green Tree and Shelterwood treatments and 40 m × 40 m in the Patch Cut and Clearcut controls. PSPs were established in the Patch Cut leave areas. In the main plots all stems >17.5 cm diameter at 1.3 m (DBH) were measured. In addition, 3.99 m radius plots were established to measure all stems <17.5 cm DBH and >1.3 m height (four in the 40 m × 40 m plots and six in the 80 m × 80 m plots). Table 1 shows the main plot and Table 2 the sub-plot data. In addition, the leave trees were spatially mapped for location in the main plot. Data in both tables apply specifically to the PSP and may differ from the inventory figures reported by Beese (1995) for the entire treatment area.

Table 1 shows that 8% of the stems and 10% of the volume was left post treatment in the Green Tree treatments. Forty percent of the stems and 28% of the volume was left in the Shelterwood treatments. Table 2 shows that 17% of the sub-plot stems remained post treatment in the Green Tree; about one half were undamaged (damage=scar, bent, dead or cut). Thirty one percent of the stems survived in the Shelterwood treatment, of which about three quarters were undamaged.

Table 1. Pre- and post-treatment summaries for main plots (all trees >17.5 cm diameter at 1.3 m)

Treatment	Pre/Post	Stems/ha	Volume (m ³ /ha)	Species (in order)	Species %	Dominant height (m)
GT1	Pre	319	1003	HBC	56, 29, 15	43
	Post	22	110	HBC	55, 44, 1	–
GT2	Pre	341	1024	CHB	51, 36, 14	41
	Post	28	119	CHB	65, 33, 3	–
GT3	Pre	422	888	CHB	49, 38, 11	40
	Post	28	53	HCB	53, 38, 7	–
GT mean	Pre	361	973	–	–	–
	Post	26	94	–	–	–
	% left	7	10	–	–	–
SW1	Pre	309	868	HBC	50, 39, 10	40.2
	Post	125	326	HBC	47, 39, 20	–
SW2	Pre	400	928	HBCY	41, 28, 16	40.2
	Post	181	249	HBCY	54, 34, 12	–
SW3	Pre	356	981	CHB	65, 28, 6	39.3
	Post	125	198	CHB	51, 36, 13	–
SW mean	Pre	355	926	–	–	–
	Post	144	258	–	–	–
	% left	40	28	–	–	–
PC1	Pre	331	736	BHC	41, 28, 23	38.0
PC2	Pre	331	786	CHB	48, 37, 11	38.7
PC3	Pre	350	1197	CHB	59, 33, 7	43.5
PC4	Pre	400	949	CHB	61, 20, 14	41.5
PC mean	Pre	353	917	–	–	–
OG1	Pre	375	891	HB	57, 43	43.4
OG2	Pre	381	872	HCB	38, 26, 26	34.0
OG3	Pre	350	1026	CHB	54, 28, 18	36.0
OG mean	Pre	369	930	–	–	–

PC = Patch Cut, SW = Shelterwood, GT = Green Tree,

H = western hemlock, B = amabilis fir, CY = yellow cypress, C = western redcedar.

Volume is all trees >17.5 cm at 1.3 m height, less 30 cm stump, to 10 cm top. No deduction for decay.

Table 2. Pre- and post-treatment summaries for sub-plots (all trees >1.3 m tall and less than 17.5 cm diameter at 1.3 m height)

Treatment	Pre/ Post	Stems/ ha	Volume (m ³ /ha)	Species (in order)	Species %	Height growth (cm/yr)	Branch growth (cm/yr)	Munsell's colour rating
GT1	Pre	1067	6.5	BHC	81, 14, 4	2.6 (1.2)	7.5 (0.6)	5GY5/9
	Post all	233	0.2	BH	50, 50			
	Post un	33	0.0	B	100			
GT2	Pre	867	18.6	HB	71, 29	0.9 (0.1)	4.9 (0.5)	5GY5/9
	Post all	166	0.2	B	100			
	Post un	33	0.0	B	100			
GT3	Pre	1133	23.0	BHC	79, 12, 9	1.3 (0.4)	5.4 (0.7)	5GY5/8
	Post all	133	0.6	B	100			
	Post un	67	0.0	B	100			
GT3 mean	Pre	1022	16.0	—	—	1.6 (0.6)	5.9 (0.6)	5GY5/9
	Post all	177	0.3	—	—			
	Post un	44	0.0	—	—			
	% left all	17	—	—	—			
SW1	Pre	1333	22.0	BH	73, 27	3.0 (1.6)	7.2 (1.5)	5GY4/6
	Post all	867	11.0	BH	79, 21			
	Post un	767	10.0	BH	78, 22			
SW2	Pre	1433	17.7	BH	84, 16	2.0 (0.7)	6.6 (0.7)	5GY4/6
	Post all	299	1.8	BH	66, 34			
	Post un	200	0.2	B	100			
SW3	Pre	1700	20.9	BH	95, 5	2.8 (1.0)	5.7 (0.8)	7.5GY4/6
	Post all	233	1.8	BH	75, 25			
	Post un	33	0.0	B	100			
SW mean	Pre	1489	20.2	—	—	2.6 (1.1)	6.5 (1.0)	5GY4/6
	Post all	466	4.9	—	—			
	Post un	344	3.4	—	—			
	% left all	31	—	—	—			
PC1	Pre	1150	22.8	BH	75, 25	0.8 (0.3)	3.1 (0.8)	5GY5/6
PC2	Pre	850	14.7	BH	74, 26	1.7 (0.1)	4.0 (0.3)	5GY5/9
PC3	Pre	1350	8.9	BH	63, 27	0.6 (0.4)	3.7 (1.2)	7.5GY4/6
PC mean	Pre	1117	15.5	—	—	1.0 (0.4)	3.6 (0.8)	5GY5/7
OG1	Pre	680	11.1	BH	59, 41	—	—	—
OG2	Pre	1250	15.2	BH	63, 37	—	—	—
OG3	Pre	600	6.1	HB	52, 48	—	—	—
OG mean	Pre	843	10.8					

See Table 1 for abbreviations. Pre is pre-treatment, Post all includes all stems after treatment, Post un is undamaged trees and includes all stems post treatment undamaged (damage = bent, scar, dead top, cut) by logging. Average yearly height and branch growth and colour for amabilis fir only, standard error in brackets.

Permanent Sample Plots

Figure 1 shows volume, growth and stems per ha (sph) data for natural amabilis fir PSPs maintained by MacMillan Bloedel in the montane variants. Although these PSPs were established in fully stocked stands to help develop natural stand yield tables they do show some excellent volume growth (over 10 m³/ha/year) and high densities (over 5000 sph). Note that the older PSPs were established at higher elevations on old slides or burns/bug-kills so may not be representative of the next rotation. These data form a touchstone comparison because they are clearcut-unburned sites that can be compared to our alternative silviculture systems.

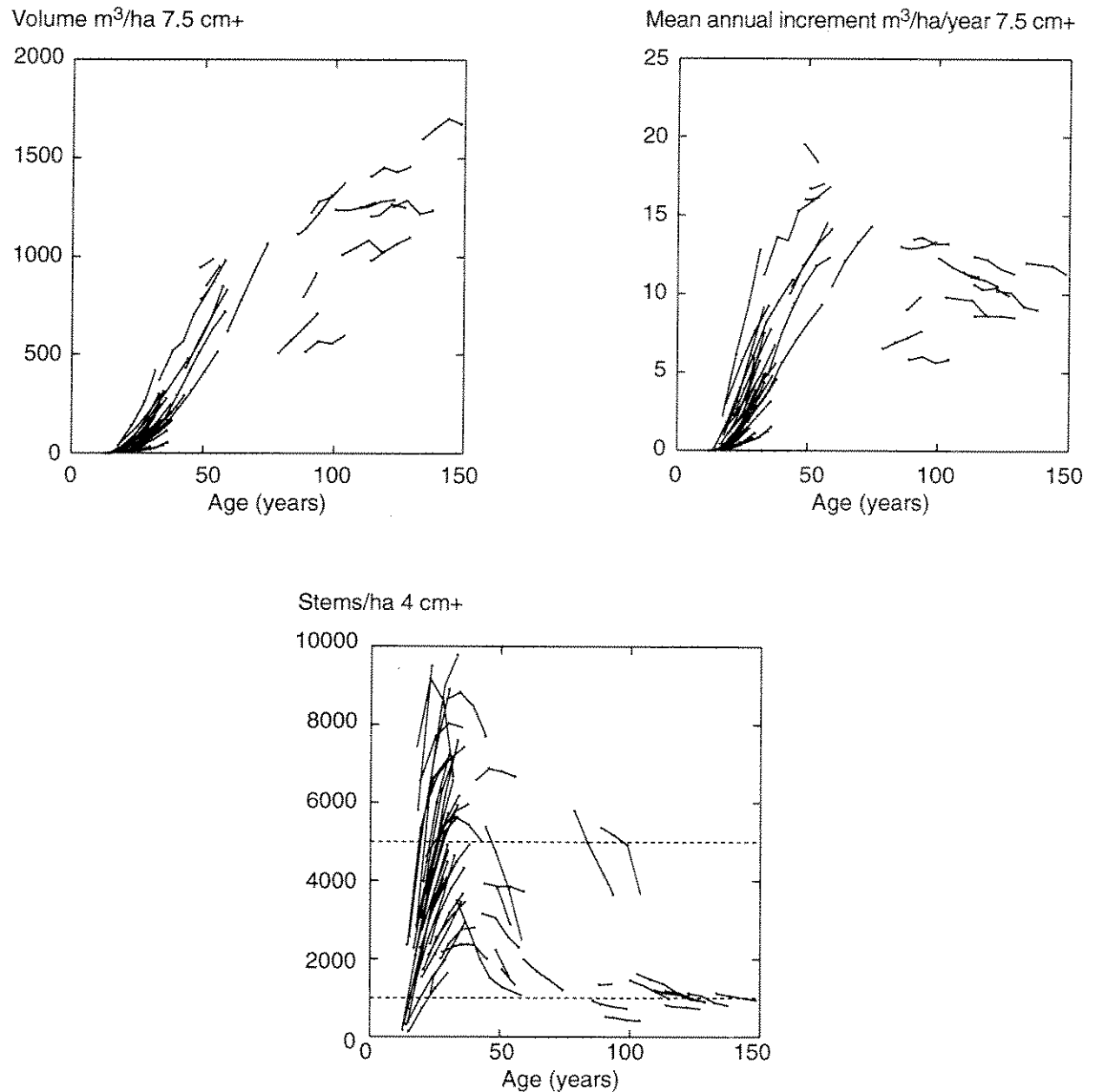


Figure 1. Volume, mean annual increment and stems per hectare for montane variant amabilis fir PSPs.

Regeneration Concerns

The basic regeneration concerns are connected with the harsher environments at higher elevations. Some manifestations include: irregular height growth, patchy stocking with very high-density clumps and foliage chlorosis (Arnott *et al.*, 1995; Koppenaal and Mitchell, 1992). The irregular height growth and patchy stocking of amabilis fir is a rule rather than an exception. Figure 2 shows some height growth trends for a stand sampled close to the MASS site. This erratic growth of amabilis fir is very common throughout the montane forests of Vancouver Island and may not pose any threat to long-term stand growth.

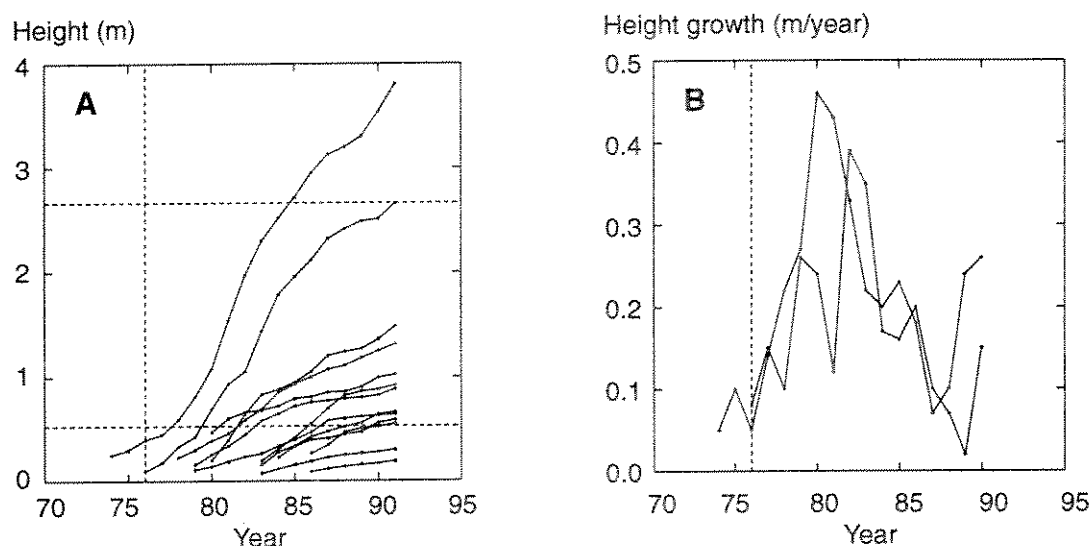


Figure 2. Graphs of amabilis fir height and height growth patterns in a 4 m × 4 m plot in an unburned clearcut logged in 1976 near the MASS site. Notice the irregular height growth in A. The growth rate of the two largest trees shown in A is illustrated in B. Notice the different growth patterns in these two neighbours.

Conclusions

It is too early to make predictions about regeneration and growth response in montane forests to alternative silvicultural systems. There is little information available. The above PSP data and other observational evidence suggests that previously clearcut and unburned stands can show good growth rates and very high stocking. Only a few of the PSPs are above 1000 m in the Mountain Hemlock biogeoclimatic zone, which is perhaps where future work should be concentrated.

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Hemlock Dwarf Mistletoe and Decay Organisms Associated with Western Hemlock and Amabilis Fir at the Montane Alternative Silvicultural Systems (MASS) Research Site in Coastal British Columbia

*R.J. Nevill and C. Wood
Canadian Forest Service
Pacific Forestry Centre
506 West Burnside Road
Victoria, B.C. V8Z 1M5*

Introduction

Alternative harvesting systems to clear-cutting may be carried out for many reasons including reducing visual or environmental impacts and compatibility with other forest uses. However, alternative harvesting systems may require multiple stand entries providing the potential for damage and decay to residual crop trees (Alexander 1986). In addition, in coastal areas residual crop trees may be infected with hemlock dwarf mistletoe, *Arceuthobium tsugense* (Rosendahl) G.N. Jones, which may cause mortality and growth reduction to the regenerating stand (Thompson *et al.* 1983). Although volume loss to decay and dwarf mistletoe was expected to decrease with the conversion of old-growth stands to managed forests, these predictions were based on the continued use of clear-cut harvesting.

Renewed interest into alternative silviculture systems to clear-cut harvesting, and the Montane Alternative Silvicultural Systems (MASS) research initiative (Beese 1995), provides an opportunity to investigate tree decay associated with wounding as well as the spread of hemlock dwarf mistletoe in the montane ecosystem. A preharvest timber cruise and subsequent harvest revealed that dwarf mistletoe and decay were present on the site. Identification of decay fungi and residual trees with mistletoe at the site would provide baseline data for comparisons of decay fungi and spread of hemlock dwarf mistletoe at other coastal montane sites as well as for comparison with sites at lower elevations.

Methods

The MASS research site is located in the Montane Moist Maritime Coastal Western Hemlock biogeoclimatic variant (CWHmm2) (Green and Klinka 1994) in the Iron River Operation of MacMillan Bloedel Limited, Menzies Bay Division, south of Campbell River, B.C. Three alternative silviculture systems were tested: 1) Patch Cut (PC – three small 1.5 ha openings in each replicate of the treatment); 2) Green Tree Retention (GT – retaining 25 trees/ha); and 3) Shelterwood (SW – retaining 200 trees/ha or 30% of the basal area of the original stand). Each alternative silvicultural treatment block was 9 ha and each treatment was replicated three times. A 69 ha clear-cut and 20 ha old-growth stand served as control areas.

Dwarf Mistletoe Survey

Each of the alternative silviculture system treatment blocks was surveyed by the transect system as this was determined to be the most appropriate method to provide an overview of dwarf mistletoe in each block. The width of the transects varied as follows: in the Old-Growth stand, Shelterwood and Patch Cut reserve transects were 10 m wide, and in the Green Tree Retention they were a minimum of 50 m wide to bring in as many of the hemlock on the site as possible. Trees were tallied by dominance, and dwarf mistletoe infection was rated by severity of stem and branch infections in each third of the crown (Smith 1969).

Stem Decay Survey

Sixty-eight windfelled trees, 29 amabilis fir (*Abies amabilis* Dougl. ex Forbes) and 29 western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), were sampled for decay and decay organisms. Windfelled trees were sampled so as not to disturb other research being conducted on site. All sample trees had been windthrown in the year after harvest and still had green foliage; therefore, the decay sampled occurred in living trees.

Trees with visible decay indicators, such as conks, fork tops, crooks, and frost cracks etc. were preferred, however, as few windthrown trees had indicators, most trees were chosen at random. For each tree, the diameter at breast-height (DBH), height, and the presence or absence of decay indicators were recorded.

To determine the presence and extent of decay, trees were bucked every 2 m up to the living crown. If decay was detected, a 5 cm disk sample was removed every 2 m until the presence of stain or decay was no longer detectable. Sample discs of decayed wood were removed to the Pacific Forestry Centre, Canadian Forest Service, Victoria B.C., for culture and identification of decay organisms. For each tree an estimation of gross merchantable volume and decay volume was calculated using the volume equations provided by Watts (1983).

The presence of decay organisms was determined by isolation of the fungus from sample chips taken from stained and decayed disks. Chips were placed on 1.5% malt agar amended with 5 ppm (a.i.) benomyl in plastic petri plates. Typically, stain or decay was in one continuous area of the disk. However, when more than one area with stain or decay was present, each was sampled. After 10-20 days incubation at room temperature, the petri plates were examined for morphological features of developing fungal colonies. Decay fungi were identified using keys developed by Stalpers (1978) and Nobles (1948, 1965).

Results

Dwarf Mistletoe Survey

Dwarf mistletoe infected western hemlock trees were observed in seven of the nine treatment blocks (Table 1). No mistletoe infected trees were recorded in two Green Tree blocks (GT2, GT3) and only 3% of the trees infected in the third block (GT1). All infected trees were dominant, but infections were light (less than half the branches infected) and all infections were in the lower third of the crown.

Table 1. Incidence of western hemlock dwarf mistletoe at the Montane Alternative Silvicultural Systems (MASS) Site, 1994

Silvicultural system/ treatment block	Dwarf mistletoe infection (percent)							Dominance of infected trees ¹			
	No. of trees	Total infected	Light	Mod.	Severe	Branch	Stem	D	CO	I	U
Green Tree											
GT1	55	13	13	0	0	13	0	13	0	0	0
GT2	72	0	0	0	0	0	0	0	0	0	0
GT3	83	0	0	0	0	0	0	0	0	0	0
Total	210	3	3	0	0	3	0	3	0	0	0
Shelterwood											
SW1	92	16	9	7	0	16	0	9	5	1	1
SW2	141	2	1	1	0	2	0	0	1	0	0
SW3	132	3	0	3	0	3	0	0	3	0	0
Total	365	6	2	4	0	6	0	3	3	t²	t
Patch Cut³											
PC1	227	25	7	13	5	24	1	2	11	8	5
PC2	273	5	4	t	t	4	1	1	1	1	1
PC3	240	26	0	24	2	25	1	1	8	8	8
Total	740	18	4	12	1	17	1	1	7	6	5

¹ Dominance classification: D = dominant, CO = codominant, I = intermediate, U = understory

² t = trace

³ Trees only surveyed on residual patches with standing timber

An average of 6% (range 3–16%) of the hemlock were infected in the three Shelterwood (SW) treatment blocks. Infection was light to moderate and on the lower third of the crowns. Most (90%) of the infected trees were dominant or codominant.

Infection was highest (avg. 18%, range 5–26%), in residual old growth areas in the Patch Cut (PC) blocks. Infection was severe on 13% of the trees, including stem infections on six trees. About two-thirds of the infected trees were codominant or intermediate class trees, and the remainder mostly understory.

Stem Decay Survey

Windthrown western hemlock on the site were generally larger and had more decay than amabilis fir (Table 2). *Phellinus pini* (Thore:Fr.) Ames was the most commonly recovered decay organism from western hemlock and was the second most commonly recovered decay organism from amabilis fir. Overall, this fungus accounted for 36% of all infections and over 50% of the total decay volume in both tree species (Table 3).

Table 2. Summary of the occurrence of decay in living, windthrown western hemlock and amabilis fir sampled at the MASS site, 1994

Tree species	No. of trees	No. of trees with decay	Mean DBH (cm)	Mean ht. (m)	Mean gross mer. vol. (m ³)	Mean decay vol. (%)
Western hemlock	29	11	49.5	31.5	2.19	14.29
Amabilis fir	29	5	35.5	26.3	1.29	6.89

Table 3. The occurrence of decay-causing fungi in living, windthrown western hemlock and amabilis fir trees sampled at the MASS site, 1994

Organism	Type of decay	Western hemlock			Amabilis fir		
		No. of infections	All infections (%)	Total decay vol.(%)	No. of infections	All infections (%)	Total decay vol. (%)
Root and butt rots (total)							
<i>Heterobasidion annosum</i>	white spongy	1	4.0	8.0	1	4.0	0.2
<i>Phaeolus schweinitzii</i>	brown cubical	1	4.0	2.7			
<i>Penniophora subacida</i>	white spongy	1	4.0	8.8			
Trunk rots (total)							
<i>Phellinus pini</i>	white pitted	8	32.0	47.8	1	4.0	3.7
<i>Echinodontium tinctorium</i>	red stringy	4	16.0	0.0	2	8.0	16.4
<i>Heterobasidion annosum</i>	white spongy	1	4.0	4.3			
<i>Pycnoporellus alboluteus</i>	brown cubical	1	4.0	1.2			
<i>Sparassis crispa</i>	brown carbonizing	1	4.0	2.7			
<i>Stereum sanguinolentum</i>	brown cubical	1	4.0	4.3			
Unknown		1	4.0		1	4.0	0.9
Total		20	80	80	5	20	21

Red stringy rot caused by *Echinodontium tinctorium* (Ellis. & Everh.) accounted for most of the decay volume in amabilis fir. This fungus was also recovered from dark pink-stained wood in four hemlock trees, but other than staining there was no visible evidence of decay.

Other decay fungi recovered included *Heterobasidion annosum* (Fr.) Bref., *Perennipora subacida* (Peck) Donk, *Phaeolus schweinitzii* (Fr.) Pat., *Pycnoporellus albolutens* (Ellis. & Everh.) Kotlaba & Pouzar, *Sparassis crispa* (Wulfen:Fr.) Fr., *Stereum sanguinolentum* (Albertini & Schwein.:Fr.) Fr. which were each recovered from a single tree.

Discussion

The presence of hemlock dwarf mistletoe on western hemlock at the MASS site had previously been determined by MacMillan Bloedel. Control has been successful to date during site treatments, particularly in the Green Tree blocks. Removal of infected residuals would significantly reduce any potential impact on western hemlock at the site. To ensure control is effective, periodic monitoring is recommended.

This study also identifies decay organisms affecting living western hemlock and amabilis fir at the MASS research site and provides information on decay fungi that may be found in this variant of the CWHmm2. Continued sampling at this and other sites would provide a more complete picture of the decay fungi that may be found in this montane ecosystem.

Phellinus pini was the most frequently recovered decay organism at the MASS site and this fungus was also frequently recovered in a previous study of decay fungi on Vancouver Island (Buckland *et al.* 1949). However, *Fomitopsis pinicola*, the major cause of decay identified in the previous study was not recovered from any of the trees in this study.

Echinodontium tinctorium was the second most recovered decay organism in this study. Although the fungus was recovered from stained hemlock wood these were judged to be latent infections for which no volume loss could be attributed. These results seems to fit well with the description of Thomas (1958) who noted that this fungus was common to abundant in amabilis fir, but rare in hemlock on mid-elevation coastal forests.

The presence of *E. tinctorium* on the site has implications for the alternative silvicultural systems studied on this site. This fungus infects small branch twiglets of suppressed trees which are later overgrown and incorporated into the heartwood when the tree is released. These infections may remain dormant for years until revived by a traumatic event to the tree such as a frost crack or other wound (Etheridge and Craig 1976). Aho *et al.* (1983, 1987, 1989) have reported that wounds caused by thinning or selective harvest operations may reactivate *E. tinctorium* infections and that resulting decay may be extensive. Latent infections by this fungus were present on the MASS research site which suggests that this fungus may cause decay in partially cut stands where poor harvesting practices occur in the coastal montane region of British Columbia.

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Effects of Harvesting and Trail Rehabilitation on Soil and Long-term Forest Productivity in Alternate Silviculture Systems Trials

*John Senyk, Don Craigdallie, and Ed Wass
Canadian Forest Service
Pacific Forestry Centre
506 West Burnside Road
Victoria, B.C. V8Z 1M5*

Introduction

Ground-based harvesting systems most often result in soil disturbance which may be either beneficial or detrimental to tree growth. The extent and severity of this disturbance varies with slope, soil type, moisture conditions, yarding method, equipment, silviculture system, etc. The major concerns are disturbances such as soil compaction, soil displacement, (soil erosion, nutrient depletion, changes in site hydrology and site microclimate) that may result in on-site long-term forest productivity losses. Most of the experience with "soil disturbance plantations" gained to date has been from the Interior of the Province and has dealt with clearcut harvesting and steep slopes. The past decade or so has seen a few studies on the Coast that have looked at equipment impacts and monitored the effects on long term growth. One or two of these were strictly experimental, others operational, but all involved clearcuts.

There is ample evidence that clearcuts, above 700 m in the Coastal Montane, are difficult to regenerate and that seedling growth rates are poor. Alternative silviculture systems may create favourable environments within the "partially cut" stands that could improve seedling survival and long-term performance. However, the use of ground-based equipment within the stand at any phase of the harvesting and yarding operation may result in soil disturbance which could have a negative impact on any gains in growth and/or survival made through manipulating the overstory.

Until recently, a commonly held view was that inherent soil productive capacity is a constant and that simply by scheduling harvests and prompt reforestation, a sustained yield of forest products could be achieved. Recent evidence indicates that soil productive capacity is neither unlimited nor constant and that forestry practices can indeed negatively affect soil productivity over the long term (Dyck *et al.* 1994).

Forest management is viewed as a continuum or sequence of related operations: from access (road construction), harvesting, preparing, planting, caring, etc.; a whole series of events affecting portions of landscapes at any one time. The cumulative effects of these practices on the soil (ecosystem) can be significant.

The silviculture system practiced, type kind and number of entries, and rotation age, will determine the kinds and intensity of soil disturbance and the time frame allowed for recovery. Everything points to future forestry practices that will greatly increase the potential for detrimental effects through more intensive practices that require more entries at shorter intervals. These, in turn, will generate a need for corrective measures in the form of site preparation and rehabilitation practices which could further accentuate soil disturbance if not carefully matched to the site and disturbance type.

The MASS trials have allowed for the study of site specific, cumulative effects of harvesting and rehabilitation practices on the soil, under different silviculture systems. Studied, were four silviculture systems (SS) or treatments comprised of Clearcut (QB,SL); Patch Cut (PC) in which 50% of the area was harvested in clear felled patches 1.5 ha to 2 ha in size; Green Tree (GT) essentially a clearcut with uniformly spaced live standing trees left and Shelterwood (SW) in which about 70% of the basal area was removed leaving about 200 stems/ha. The trials also provided for an opportunity to establish "soil disturbance" plantations which have allowed the measurement of growth response and hence a means of evaluating changes in soil productive capacity. Year-round monitoring of various microclimatic parameters, on disturbed and undisturbed soils, has provided environmental data to assist in evaluating seedling performance.

Site Description

Soils on the MASS site are developed in morainal material, derived from sedimentary bedrock. The parent material is relatively fine textured and calcareous. Soils are generally deep >1m, Orthic and Gleyed Ferro-Humic Podzols (Ag. Can. 1987) with a weakly to moderately developed duric (cemented) horizon. Textures range from sandy loam to clay loam being loam for the most part, coarse fragment content ranges from 20% to 50% and soil drainage varies from well drained to poorly drained (Chatterton, *et al.* 1981). Microtopography is complex with frequent well drained hummocks interspersed with moist to wet depressions. The humus layer (Orthic and Ligno Humimors) averages 15 cm to 30 cm, being shallower in the clearcut blocks and thicker on the part-cut treatments. Hemic and Lignic Folisol soils (> 40 cm) occur sporadically throughout, but again are most common in the part-cut blocks. Turbated soils, accompanied by frequent voids, indicative of past windthrow events, occur throughout. Tree roots are concentrated in the humus layer being much less abundant in the upper 50 cm of mineral soil. Charcoal is occasionally evident at the interface of the humus layer and mineral soil.

The thick humus layers at the surface tend to intercept and absorb moisture till saturated. The mineral soils are moderately pervious in the upper horizons and become less so with depth. During snow melt and periods of heavy precipitation, surface runoff is common and subsurface lateral seepage at the contact with the weakly cemented (duric) layer and/or C horizon nearly continuous. This subsurface seepage, which continues long after inputs from snow-melt and/or precipitation have ceased, is most evident in moisture receiving positions in the partial cut blocks.

Methods

Soil Assessment

Pre-harvest

Sampling for soil classification and bulk density was undertaken immediately after road access to the blocks was established. Sample sites were chosen based on soil-ecosystem strata typified by soil drainage differences—dry to wet. Sampling sites were tied to an established grid network for future reference (Phillips 1995). Soil pits were excavated to bedrock, C horizon or to a duric layer (minimum 50 cm into mineral soil if possible). Soils were classified and horizons sampled (Ag. Can. 1987) in at least two sites within each soil-ecosystem stratum. Soil bulk density using the excavation sand cone technique (Klute 1986), was sampled at two spots within each pit. The humus layer was sampled in 10 cm increments down to the mineral soil interface. The upper 20 cm of mineral soil was sampled in 5 cm increments and below that in 10 cm increments.

Post-harvest

Sampling was designed to capture the range of soil disturbance types within the ecosystem strata identified above. Soil pits were located as close as possible to the pre-harvest excavations on "homogenous" sections of skidtrail that would accommodate long-term plantation studies. Skidtrail cross-sections were excavated and both tracks, between tracks and adjacent undisturbed were sampled. All sampling was replicated within treatments. Climate stations were established near the excavations and sensors placed to monitor various above and below ground parameters in both disturbed and undisturbed soils, year-round. Skidtrail rehabilitation was carried out on portions of trail immediately adjacent to the sampled and planted skidtrails or near skidtrails with similar ecosystem characteristics (Warila and Boyle, 1995). Five rehabilitated trail cross-sections were excavated and sampled for bulk density calculation and chemical and physical analyses. Sampling was undertaken within two months of the rehabilitation work so it is not likely that soils would have had much opportunity to reconsolidate to any extent.

Productivity Assessment

Effects of management practices on soil can be assessed directly, however in order to evaluate any changes in soil productive capacity, tree growth response to these changes needs to be measured. There are no currently available techniques that can reliably identify complex soil chemistry and biological activity that affect mineralization and availability of nutrients and conditions for root growth. Any plant-independent evaluation of soil productivity can only provide circumstantial evidence of productivity change (Dyck, *et al.* 1994).

Seedlings (alternating western hemlock 1-0 415 plug, and Amabilis fir 1-0 313b plug) were planted during the first and second week of May, 1994. Seedlings were planted in rows along skidtrail tracks, in the centre of the trail between the tracks and on both sides of skidtrails in undisturbed areas. Heavy slash was removed from planting sites in undisturbed areas; however, planting spots in the undisturbed were not screefed nor was any special effort made to choose microsites. Rather seedlings were planted randomly at a relatively uniform spacing. Rehabilitated trails were planted in the same way as the skidtrails with rows corresponding approximately to track and between track locations only. All trials were replicated within and between treatment blocks. All seedlings were planted by the same individuals to avoid, as much as possible, potential variability introduced by planting technique. A total of 1840 seedlings were planted in all treatments (920 each of hemlock and fir).

Seedling heights and basal (ground level) diameters were measured immediately after planting and health and vigor assessed. Seedlings were remeasured after 1 year in the spring of 1995, prior to flushing.

Results

Undisturbed total and fine soil bulk density values for both the humus and mineral soil, sampled from all treatments prior to logging, are shown in Figure 1. Figure 2 shows the percentage change in total soil bulk density of the track and between track disturbance classes when compared to the undisturbed. Increases in total humus bulk density ranged from about 20% to almost 90%. In other than the most severely impacted trails, where the humus may have been mixed with mineral soil and/or woody debris, compacting the humus layer did not greatly decrease its total percent porosity (Figure 3).

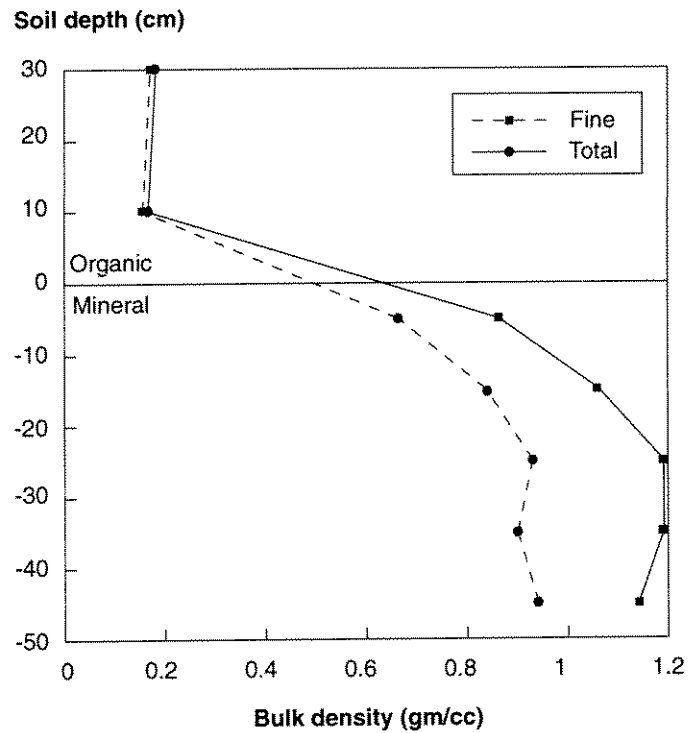


Figure 1. Average inherent total and fine soil bulk density by 10 cm depth increments.

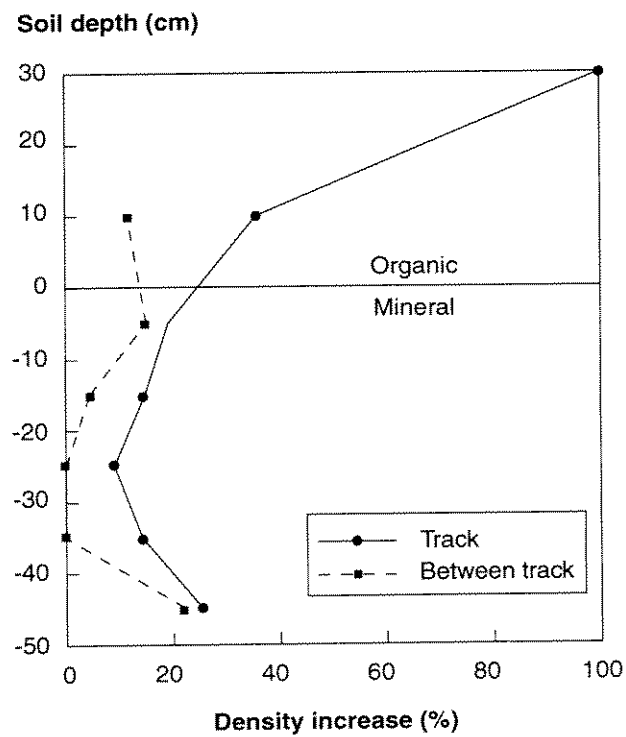


Figure 2. Average total soil bulk density increase on skidtrail track and between track.

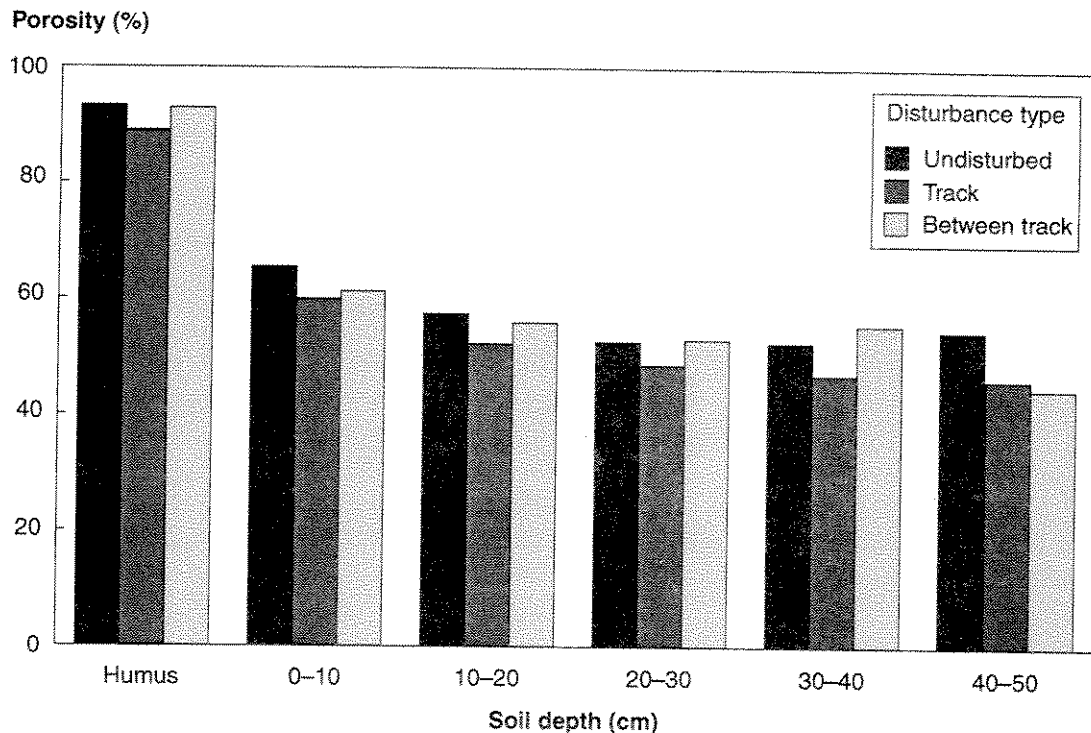


Figure 3. Percent porosity by disturbance type and 10 cm increments.

Preliminary indications were that the total soil bulk density on the rehabilitated trails was similar to and occasionally greater in the upper 20 cm and the percent porosity less than on the skid trail track itself. This could indicate that the rehabilitation technique excavated dense subsoil and deposited it at the surface or that simply lifting the soil with the shovel and redepositing it, did not necessarily fully decompact it.

Height of western hemlock seedlings, after one growing season, is shown in Figure 4. Average height by disturbance class was greatest on the undisturbed and least on the rehabilitated trail sections across the range of silviculture systems or treatments. Seedlings, planted on track and between track positions, performed equally well except in the Patch Cut treatments where the between track seedlings did best.

Percentage survival of western hemlock is consistently lowest on tracks, particularly in those treatments where yarding corridors were traveled by both a back-hoe and tracked skidder (KMC). On rehabilitated trails, in moisture receiving sites, survival of western hemlock was extremely low, below 60% (Figure 5).

Average Amabilis fir height (Figure 6) was similar across the range of disturbance classes and silviculture systems or treatments. The percent survival (80%+) of Amabilis fir (Figure 7) is relatively uniform across all treatments and differs little with disturbance class.

Climatic parameters, monitored near skidtrail plantations showed considerable machine travel impact differences between treatments.

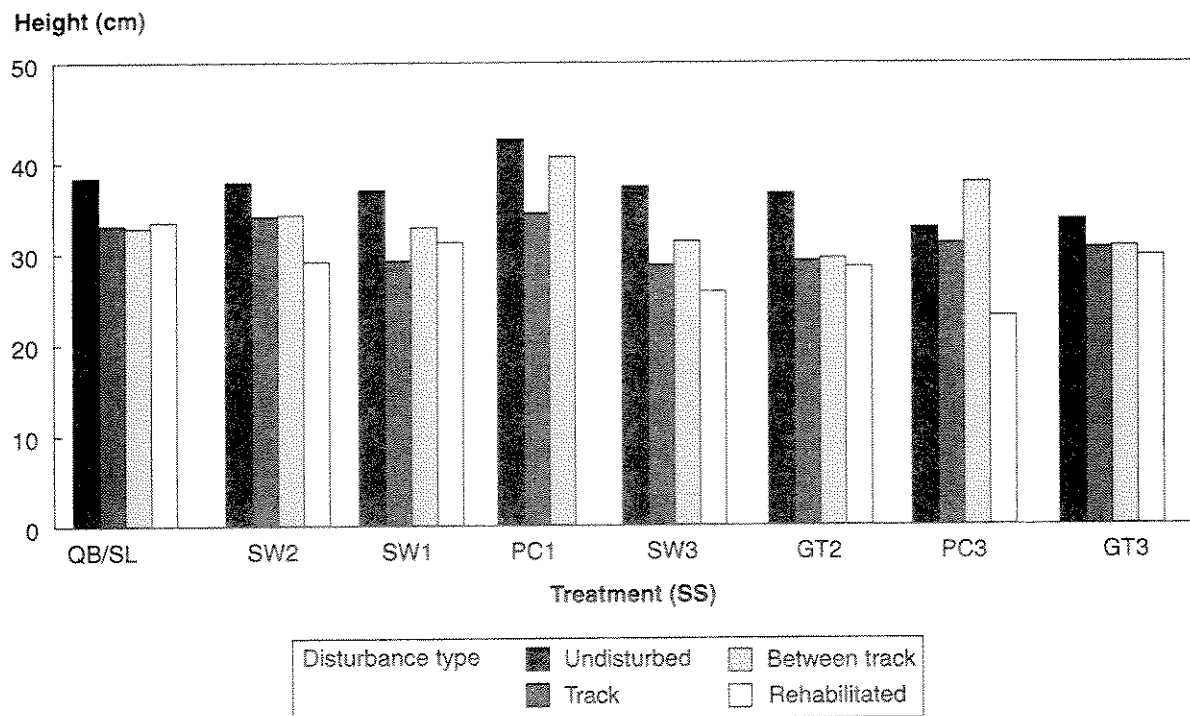


Figure 4. Total height of western hemlock by disturbance type and treatment after one growing season.

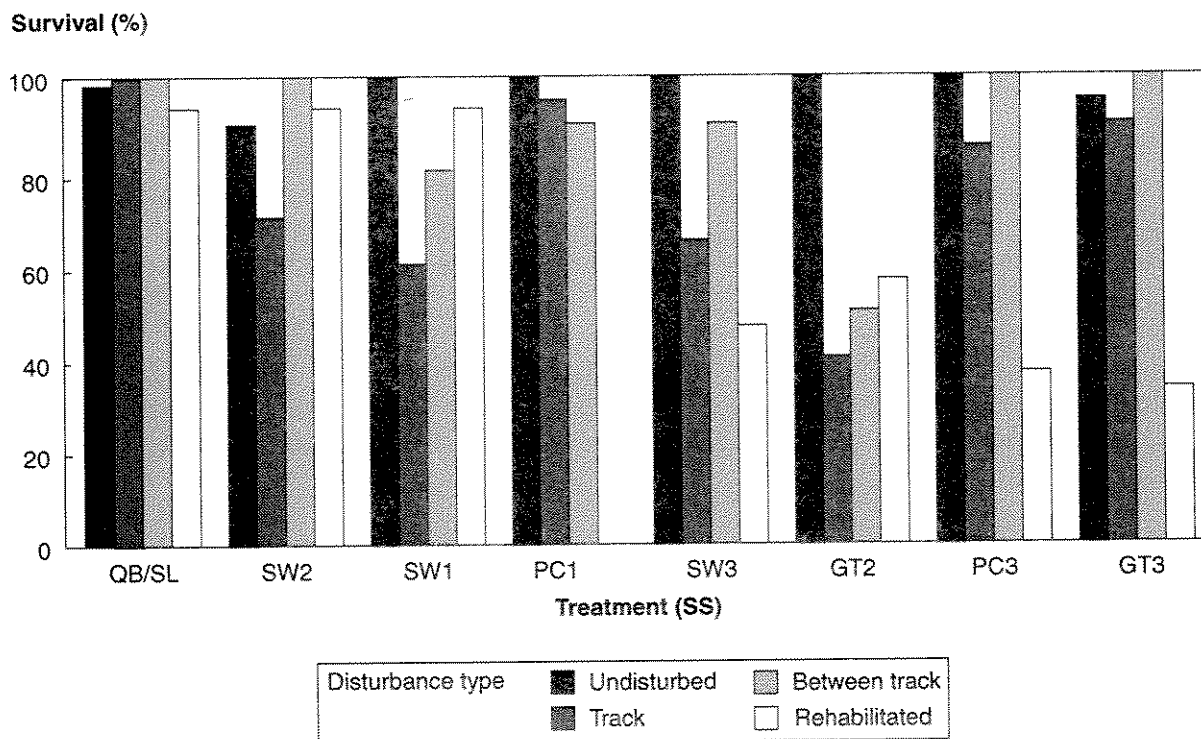


Figure 5. Percent western hemlock seedling survival by disturbance type and treatment after one growing season.

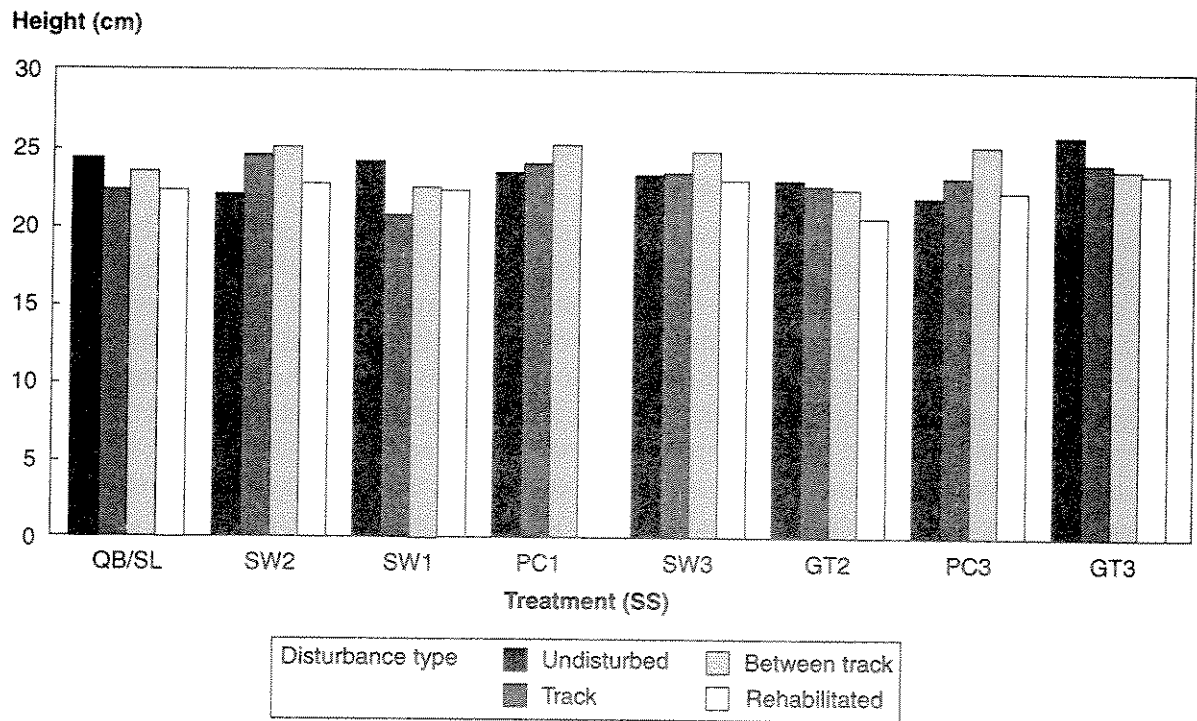


Figure 6. Total height of *Amabilis fir* by disturbance type and treatment after one growing season.

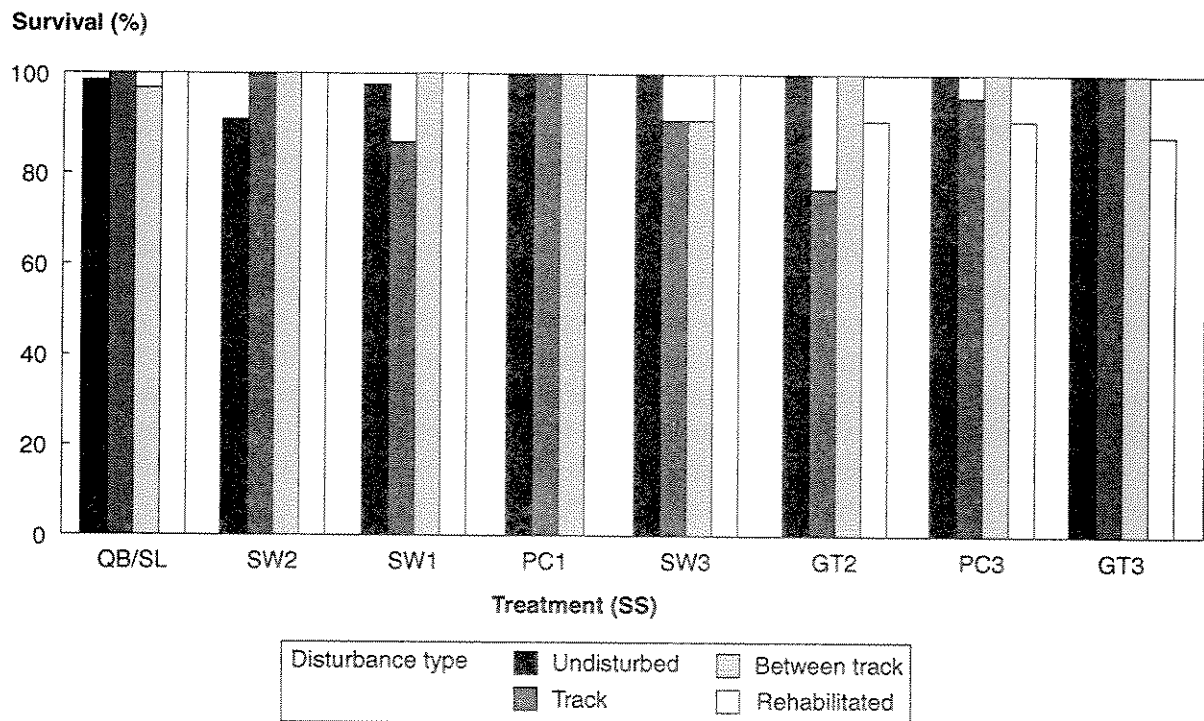


Figure 7. Percent *Amabilis fir* seedling survival by disturbance type and treatment after one growing season.

Discussion and Conclusions

The impacts of harvesting on "site quality" are manifested through nutrient removal in biomass, soil physical damage, nutrient redistribution and microclimatic modification. Other management practices such as mechanical site preparation and rehabilitation activities can also affect site quality and may have as much or more impact.

Despite the size of the excavator (Thunderbird 1146) used in forwarding wood to roadside, the relatively thick humus layer laden with roots and the heavy slash loading, following limbing and bucking at the stump, provided a high level of floatation for equipment travel. This, coupled with the single pass nature of much of the hoe-forwarding operation, created minimal mineral soil compaction and/or displacement except in turns, on slopes and in wet depressions. Where the KMC was used by itself or in conjunction with the hoe, as in the Shelterwood treatments, trails or corridors were generally traveled two or more times and mineral soil compaction was more severe; however, soil displacement except in wet areas was minimal. Modification to surface and near surface drainage such as flow interruption and damming did occur in areas traveled.

Soil compaction was the disturbance type most commonly associated with the harvesting operation at the MASS site. Compaction caused a reduction in total soil porosity. This in turn lead to slower movement of air and water in the soil and restrictions to root and mycelial penetration causing potentially negative effects on tree growth. Overall increases in total and fine mineral soil bulk density in skidtrail tracks at the MASS site ranged from 15% to as high as 50%, from about .90 gm/cc to about 1.3 gm/cc within the top 20 cm to 30 cm. Although statistically significant increases, values in most cases did not reach the critical or threshold levels of 1.4 gm/cc and above (Lewis *et al.* 1991) that would impede root development. (A wide range of threshold values appear in the literature from 1.4 gm/cc to 1.8 gm/cc. These depend to a large extent on soil texture and plant rooting habits (Glinski and Lipiec 1990; Grevers and Van Rees, 1995). Similarly, total percent soil porosity of the upper 20 cm on the tracks was above, in most cases well above, the 35% figure considered by some to be critical to root development of various plant species (Figure 3) (Glinski and Lipiec, 1990).

Rehabilitating soils that may have suffered detrimental disturbance is part of the Pre-harvest Silviculture Prescription (PHSP) requirements in the Vancouver Forest Region. The intent of the rehabilitation guidelines is to restore, as much as possible, the inherent characteristics and productivity of the site.

Skidtrail rehabilitation at the MASS site was carried out by a Caterpillar 225 DLC (back hoe). The main purpose of the procedure was to decompact skidtrail tracks, remove excessive buried woody debris and re-establish natural drainage. The hoe would walk into a block, to the end of a trail, then work its way back out, decompressing the trail behind itself. The bucket was inserted into the trail surface, partially closed (tilted towards the machine), raised a foot or two above the original trail surface and the bucket opened to allow the material to fall back onto the trail. Often roots, coarse woody debris would be shaken clean of soil and deposited to one side of the trail. The soil generally fell near the spot from which it was excavated.

Given that the average depth of mineral soil compaction on skid trail tracks ranged between 15 cm to 25 cm, much of the shovel decompaction may have been somewhat excessive. Often, soil from 40 to 60 cm depths was brought up and deposited on the surface.

Most of the soil nutrients were incorporated within the humus and the upper 15 to 20 cm of mineral soil, (Figures 8, 9, 10, 11) and scalping, mixing or burying these surface layers with subsoil material will create an initially impoverished rooting zone for the plug seedling. Also, soil bulk density increased with depth, and bringing these naturally dense soils to the surface could further inhibit root development.

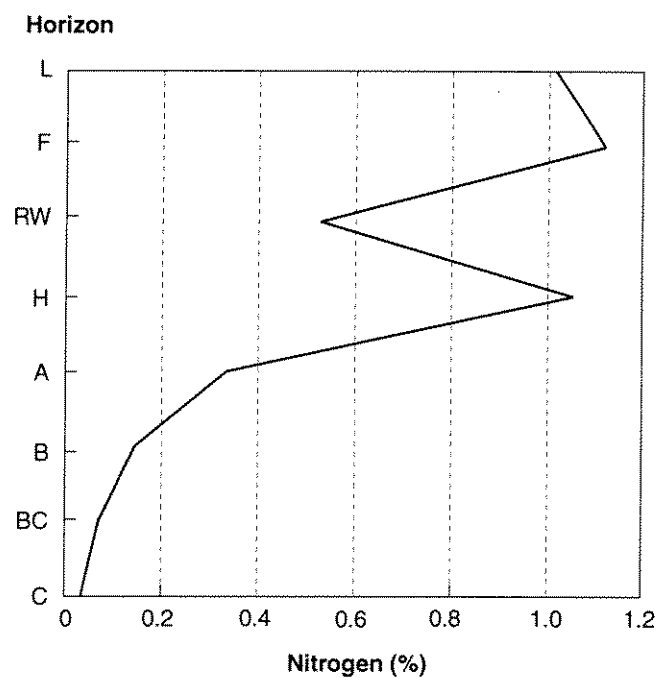


Figure 8. Percent nitrogen of undisturbed soil profile (RW=rotten wood, n=12).

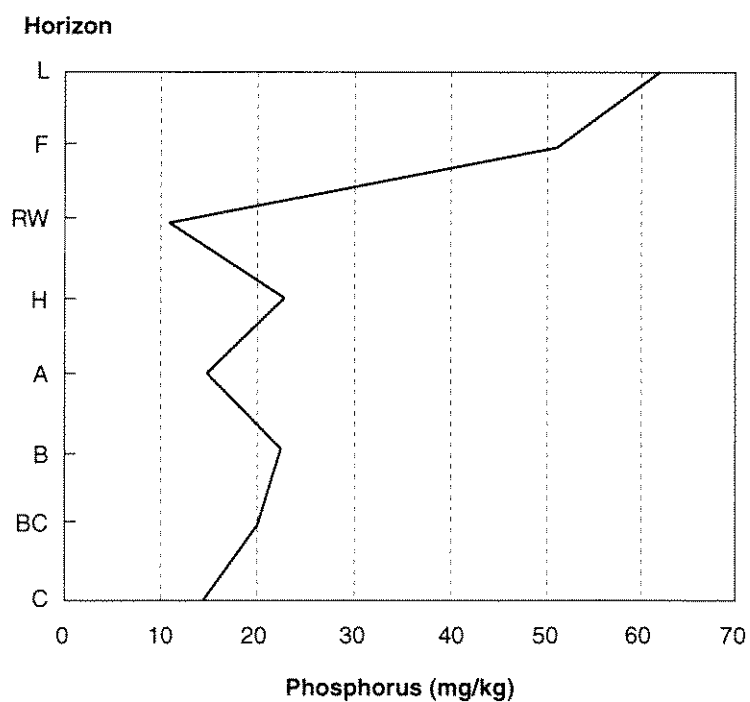


Figure 9. Phosphorus content (mg/kg) of undisturbed soil profile (RW=rotten wood, n=12).

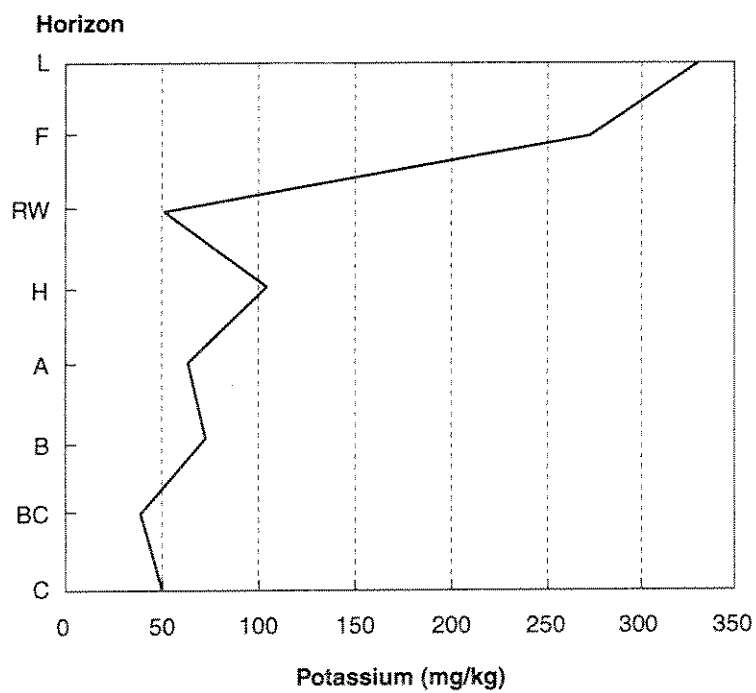


Figure 10. Potassium content (mg/kg) of undisturbed soil profile (RW=rotten wood, n=12).

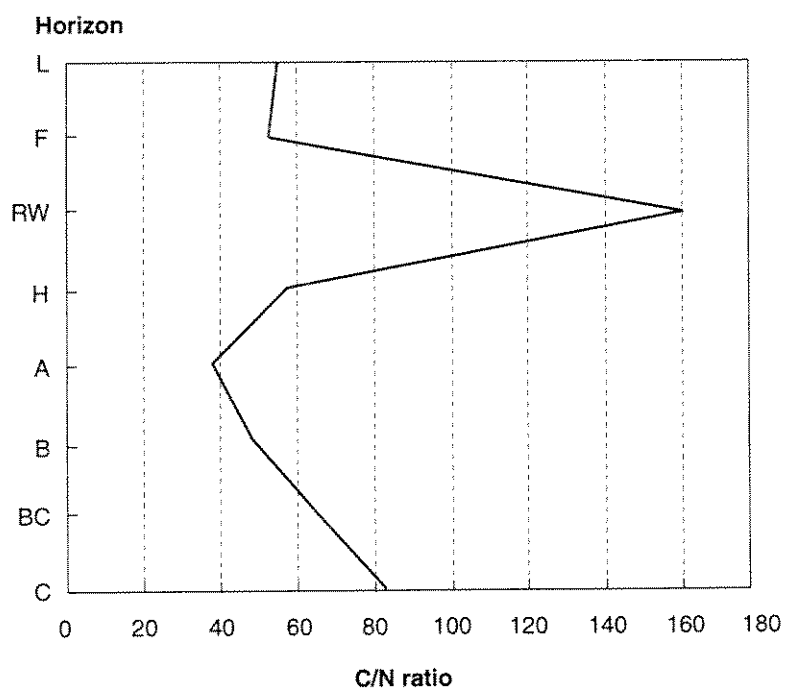


Figure 11. C/N ratio of undisturbed soil profile (RW=rotten wood, n=12).

In moisture receiving areas (imperfectly drained soils), seepage was often interrupted by deep pockets of loosened soil, forming subsurface pooling areas. Under these circumstances, soils remained saturated for extended periods of time causing severe mortality to seedlings planted on these sites (Figure 5, SW3, GT2, PC3 and GT3). In moisture shedding positions (well drained soils) where the rehabilitation was carried out as in QB, SL, SW2 and SW1 (Figure 5), the subsurface pooling did not occur.

The survival of western hemlock was greatest when planted in undisturbed to slightly disturbed humus (between tracks) and in well to moderately well drained (rehabilitated) mineral soil. Where excess moisture sat within the rooting zone for a large part of the growing season, hemlock mortality was high. On compacted soils, survival was affected across the full range of treatments. *Amabilis fir* survival was far less affected by planting position (disturbance type), soil material or moisture within the rooting zone.

Previous studies (Smith and Wass 1994; Senyk and Smith 1991) have found that seedling growth on severely disturbed soils such as compacted soils and exposed subsoils is reduced in the long term when compared to growth on undisturbed soils. These differences in seedling growth however, tend to decrease with time so that trends that appear shortly after establishment are not nearly so dramatic after 7 to 10 years. Disturbance plantations should be monitored a minimum of 10 years, preferably longer before any projections on future growth are made particularly if these are to be figured in allowable cut calculations. Despite the differences in height growth by disturbance type that appear in Figures 4 and 6 it would be premature to consider these as trends in any forecast of future performance.

Acknowledgements

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MASS: Snow Hydrology Pilot Study

*R.W. Askin and V.P. Dragunas
Land Use Planning Advisory Team
Sustainable Forestry Division
MacMillan Bloedel Limited
65 Front St.,
Nanaimo, B.C. V9R 5H9*

Introduction

It is well known that at higher elevations, more snow accumulates in open areas than under a mature forest canopy. From experience, it is common practice to observe greater snow depths in clearcut areas, than in regenerating forest stand areas. It is clear that when examining alternative silvicultural systems, it is important to be able distinguish various snow accumulation characteristics for each type of system. As a result, a MASS snow hydrology pilot study was established to examine the affects of alternative silvicultural systems on snow pack accumulations. The objective of the study was to verify where the greatest snow depths occurred, in comparison with both the Clearcut and Old Growth control areas.

Methodology

The pilot study was initiated at the MASS site in 1994. Snow courses were established within every silvicultural system. They were positioned so that geographical coverage across each site was obtained. Each survey course was distributed radially out from the centre of each silvicultural treatment. At an interval of 30 metres, twenty snow stakes were installed for each area. A total of 220 snow stakes were distributed across the MASS site (see Figure 1). Each snow stake consisted of a 2 metre metal post that was painted white, numbered, and driven into the ground surface so that it was free standing.

Once established, snow depths were surveyed once a month during the October 1994 to May 1995 period. To complete the snow depth measurements in a cost-effective manner, 8-person crews were flown by helicopter into the area. Snow surveys were carried out under favourable weather conditions, usually following significant snow storm events. Snow survey crews were dropped off in different sections across the MASS site. Measurements of snow depth were then taken along each of the established snow courses. Typically, all snow stakes were measured in one 8-hour shift. Upon completion, survey crews were helicoptered out of the area when all the measurements were completed. The net survey cost per sample period averaged \$CAN 4000.00.

Results and Observations

The results of the snow surveys for the 1994/1995 winter season are presented in Figures 2 and 3. Comparison of snow depth characteristics are graphically presented in Figure 2. Maximums, minimums, means and median snow depths are shown for each silvicultural treatment. In all cases, the minimum snow depths consisted of zero snow pack, with barren ground conditions occurring for all treatments. In contrast, maximum snow depths ranged from a low of 118 cm in the Old Growth area, to over 180 cm in the Green Tree areas. Of the six treatments, the highest snow

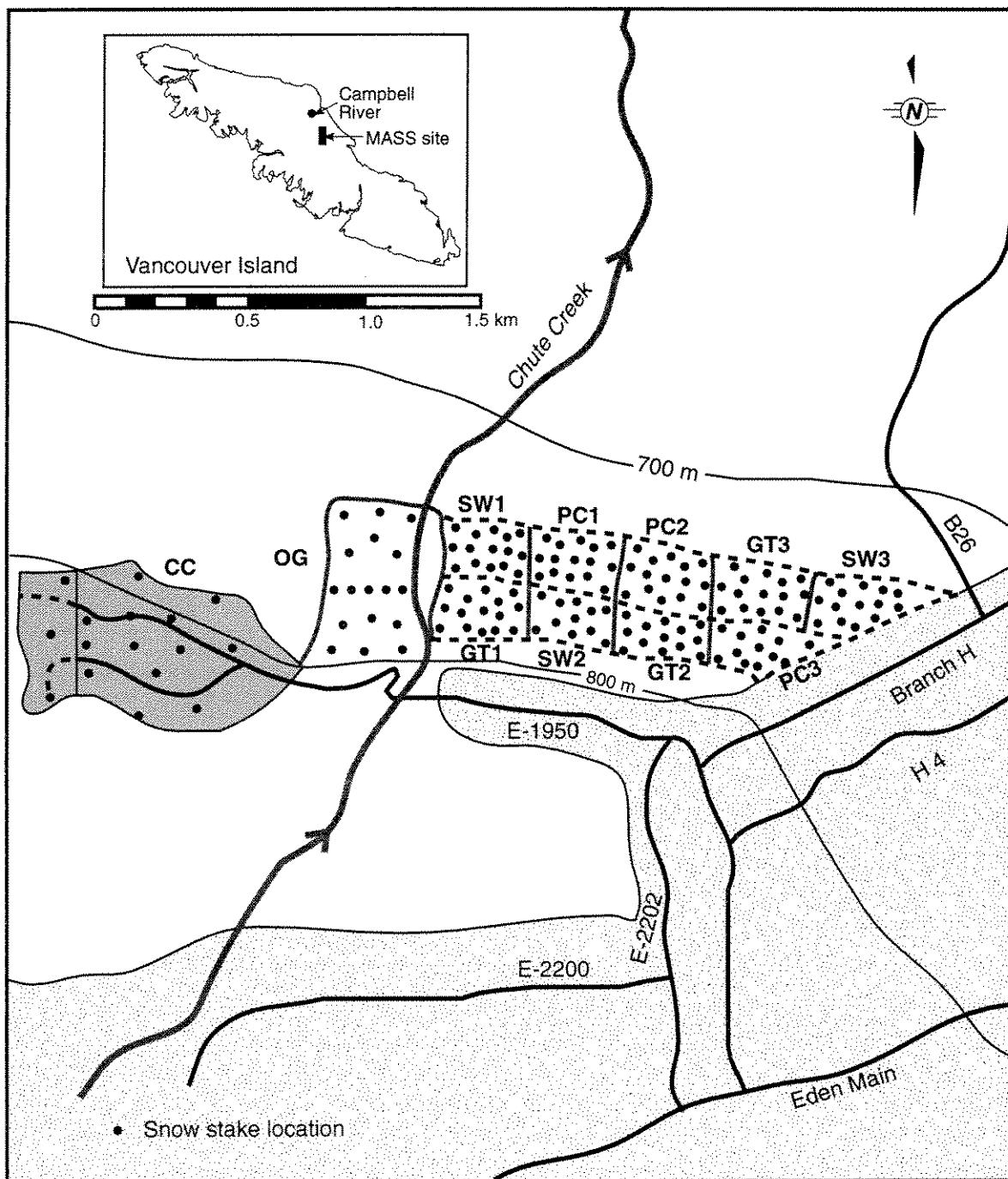


Figure 1. Location of MASS study area showing spatial distribution and intensity of snow sampling across silvicultural treatments.

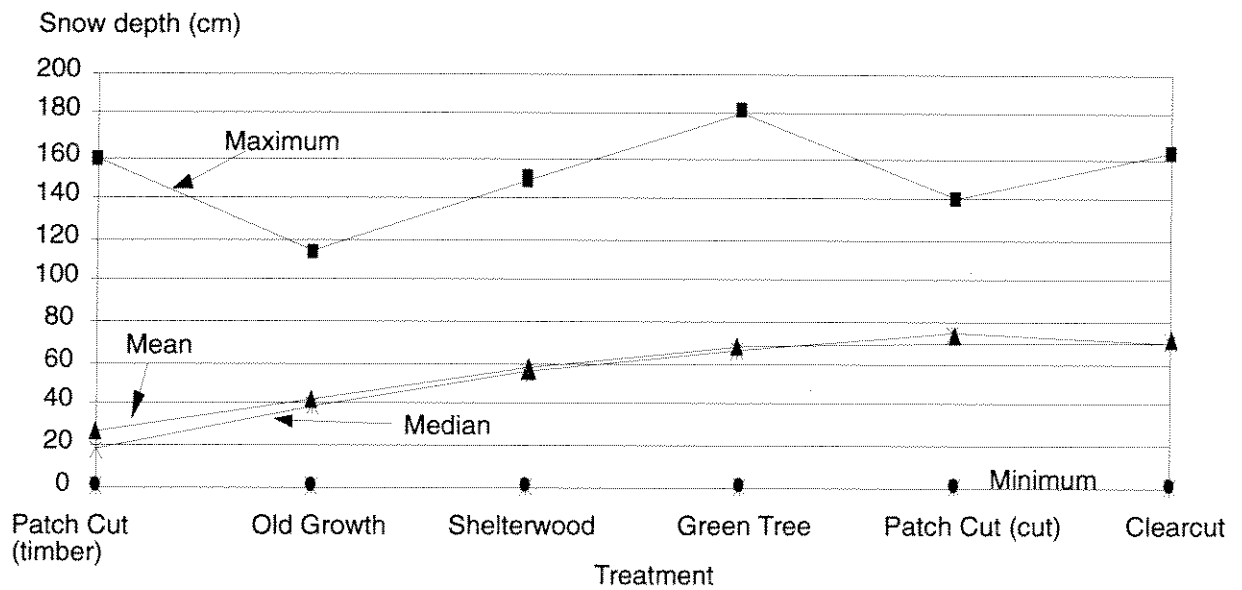


Figure 2. Comparison of snow depth characteristics for each silvicultural system.

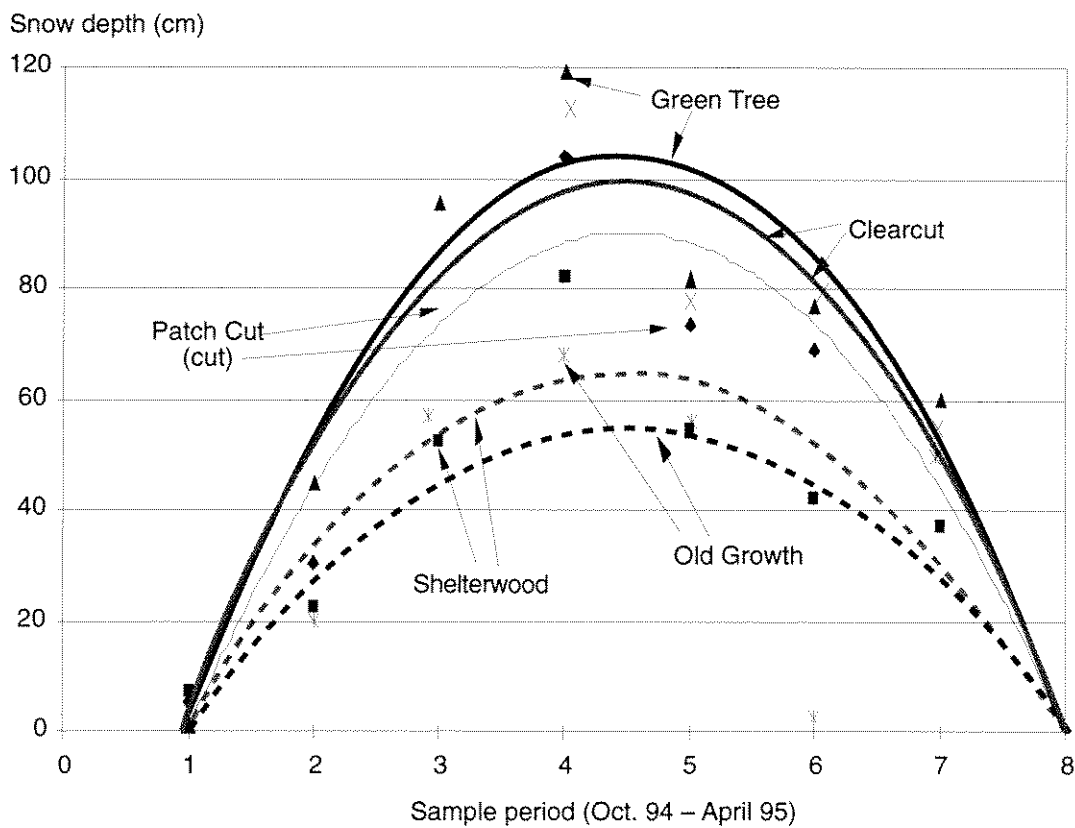


Figure 3. Average snow depth accumulations over silviculture treatments.

depth maximums were recorded within the Green Tree, Patch Cut-Cut Zones, and Clearcut areas. The lowest maximums occurred within the Patch Cut-Timber Zones, the Shelterwood and Old Growth areas.

These characteristics are further reinforced for both the mean and median snow depth results for each treatment. That is, the Green Tree, Patch Cut-Cut Zone and Clearcut areas were able to accumulate larger mean and median snow depths than the other three treatments. These results suggest that in the extreme cases, cleared areas collect approximately 2 to 3 times greater snow depths than forested areas. Shelterwood and Green Tree areas behave more as transitional snow depth accumulation zones between cleared and forested areas.

To confirm this trend, results from the first replicate of each silvicultural treatment were examined. As shown in Figure 3, snow depths reached their maximums during the mid-winter period, with Green Tree, Patch Cut-Cut Zone, and Clearcut obtaining the greatest snow depths. Both snow depth accumulation and depletion rates were highest for these silvicultural treatments. In contrast, the Shelterwood, the Patch Cut-Timber Zone, and the Old Growth had lower maximums, but more uniform snow pack accumulation and depletion rates.

Conclusions

The snow hydrology pilot study has focussed on determining where the greatest snow depths occur across the MASS silvicultural treatment areas. In comparison with the Clearcut and Old Growth control areas, the results indicate that greater snow depths occur within areas that have less amount of forest cover remaining. The more forest cover, the less amount of snow accumulations across the treatment area. Snow depths increased by an order of 2 to 3 times within the more cleared areas (Clearcut, Green Tree, and Patch Cut-Cut Zones) than with areas with more forest cover remaining (Old Growth, Shelterwood, and Patch Cut-Timber Zones).

The statistical ranges and results confirm that changes in forest coverage directly affects the snow accumulation and depletion rates for each treatment. These changes are due to alternations in energy budgets that occur geographically at the meso- and micro-scale levels between forested and cleared areas. The hydrometeorologic processes that cause these changes are reflected by changes to forest canopy snow interception, transpiration and snowmelt processes. The net result is greater snow depths in more open areas than forest covered areas.

Nitrogen Limitations on the Early Growth of Natural and Planted Montane Regeneration

R.S. Koppenaal
Silva West Consulting
954 Transit Rd.
Victoria, B.C. V8S 5A1

B.J. Hawkins
Centre for Forest Biology
University of Victoria
Victoria, B.C. V8W 2Y2

A.K. Mitchell
Pacific Forestry Centre
Canadian Forest Service
506 West Burnside Rd.
Victoria, B.C., V8Z 1M5

Abstract

Foliar nitrogen (N) concentrations were compared between natural and planted amabilis fir (*Abies amabilis* (Dougl.) Forbes) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) on clearcut, edge, and stand environments of a coastal montane reforestation site. Growth response was assessed by relative height growth rate (RGR), and dry matter partitioning in planted and natural amabilis fir, and RGR in planted western hemlock. Compared to natural regeneration released five years earlier, second-year RGR of planted amabilis fir was 67% and 58% lower on the clearcut and edge plots respectively, reflecting deficient foliar N concentrations in the planted stock the first year after planting. Root:shoot ratio in amabilis fir was lower in planted compared to natural regeneration and may have restricted access to available soil N. Nitrogen concentrations in second-year planted amabilis fir on the clearcut recovered to above the critical level indicating that microclimatic conditions on this plot increased availability of, or access to soil N. Larger root systems of planted amabilis fir on this plot probably facilitated increased N uptake. This was also true of N concentrations in natural hemlock on the clearcut which were higher than in the edge plot. Foliar N concentrations of second-year planted hemlock on the clearcut and edge plots were also deficient compared to their natural counterparts. Different yearly growth rates on the clearcut and outside edge plots may be the result of changing foliar nutrient concentrations in planted trees.

Introduction

Montane sites in coastal British Columbia present special limitations on the regeneration of shade tolerant conifers including: colder temperatures, a shorter growing season and low nitrogen mineralization rates compared to lowland sites (Koppenaal and Mitchell 1992). Growth delays of one to several years following release or planting is a common problem in shade tolerant conifers on these sites (Herring and Etheridge 1976, Wagner 1980). Growth check some years after planting has been linked to immobilization and deficiency of nutrients in some lowland plantations on northern Vancouver Island (Prescott *et al.* 1993). At higher elevations, nitrogen (N) in particular is often in low concentration in shade tolerant regeneration (Beaton *et al.* 1965, Radwan *et al.* 1989, Gessel and Klock 1982) and may be related to poor or inconsistent growth following planting or release.

In a previous study (Koppenaal *et al.* 1995) on a coastal montane clearcut, we reported that 1-year old planted amabilis fir was more chlorotic and had reduced photosynthetic rates compared to advance regeneration released four years earlier that had apparently acclimated to post-harvest conditions. Those findings prompted this study in which we compared the foliar uptake of nitrogen (N) and post-harvest growth of planted and advance regeneration of amabilis fir and western hemlock under different light environments. Our intention was to test the hypothesis that root system development in advance regeneration would allow access to a larger pool of N than was available to their planted counterparts, and that known differences in carbon assimilation under clearcut, edge and stand light environments (Koppenaal *et al.* 1995) would result in differential allocation of resources to root growth on these microclimates, thereby affecting uptake of nitrogen.

Study Area

The study site is located in the CWHmm2 biogeoclimatic variant on Eastern Vancouver Island (49°55'N/125°25'E) within MacMillan Bloedel's Iron River Operation, Menzies Bay Division. It is situated on a 7% slope facing North 20° East at 800 m elevation. Part of the study site was clearcut in 1989 and is bordered by an old growth hemlock and amabilis fir forest. Advance regeneration is primarily amabilis fir with a smaller component of hemlock.

The air temperature in the area averages 16.6°C in July and 0.4°C in January. The mean annual precipitation is 1406.0 mm (Campbell River Airport, Environment Canada). The soil is a coarse loamy Orthic Humic Podzol with a thick humus layer (14–40 cm) overlying mineral soil with stony glacial deposits and weathered bedrock.

Methods

In 1993, three plots measuring 75 m long by 5 m wide were established parallel to the north-east facing edge of an old growth stand. One plot was located 5m within the forest (stand plot), another 60 m out into the clearcut (clearcut plot), and the third plot, situated between the stand and clearcut plots, was 12 m outside the stand edge (edge plot). Each plot was subdivided into three blocks to account for within-plot variation in seedling height and nutrient concentrations. To reduce confounding effects related to the large variation in the size and age of advance regeneration on the study site, only natural seedlings under 30 cm were selected in spring 1992 for sampling. Nursery stock (1-0) of amabilis fir and western hemlock was planted on all plots on April 1993. Relative height growth rates (the natural log of the difference in successive height measurements) were calculated for 1994 from height measurements in September, 1993 and in September 1994 on planted and natural amabilis fir and planted western hemlock. Heights of 57 planted and 51 natural amabilis fir and 45 planted western hemlock from each plot were measured. Mortality and browsing resulted in uneven sample sizes among plots.

Needles were sampled for foliar N in late September 1994 from planted and natural amabilis fir and western hemlock. Current needles from 15 natural and planted amabilis fir in each plot were sampled except on the stand plot where insufficient current foliage of natural and planted regeneration resulted in sample sizes of 0 and 11 respectively. For western hemlock, difficulty in aging foliage resulted in combined current and older foliage sampled from 15 natural and planted seedlings in each plot. September 1993 foliar concentrations (amabilis fir only) were derived from bulk foliar analysis of 20 natural and planted trees from each plot. September 1994 foliar samples were analyzed for N at the MacMillan Bloedel Forest Sciences Laboratory. September 1993 foliar samples were analyzed at the Pacific Forestry Centre of the Canadian Forest Service. Total N was

analyzed using the $\text{H}_2\text{SO}_4 - \text{H}_2\text{O}_2$ digestion method and a Technicon autoanalyzer (Parkinson and Allen 1975).

Shoot and root dry weight of amabilis fir only was determined on 18 natural and planted seedlings excavated from each plot in September 1993. Samples were oven dried at 80°C , then weighed. For natural amabilis fir regeneration, dry weight was not as meaningful a criterion for between plot comparisons since the size and age of advance regeneration on the site was not uniform and sampling was restricted to regeneration under 30 cm in height measured in 1992. Dry weight sampling of natural regeneration therefore did not necessarily reflect plot differences in plant weight. Dry weight was not measured in western hemlock. Data was statistically evaluated by analysis of variance (ANOVA) to test for plot and stock (natural and planted) effects. Nested ANOVA tested for block interaction. The Tukey mean separation test was employed to identify significant differences between means (SAS Institute Inc. 1988).

Results and Discussion

Growth

Relative height growth rates (RGR) of advance amabilis fir regeneration were 3 fold and 2.4 fold higher ($P \leq 0.05$) than those of second-year (1994) planted amabilis fir growing on the clearcut and edge plots respectively (Figure 1). Scarcity of advance western hemlock on the study site precluded a comparison of height growth with planted seedlings. Second-year RGR of planted western hemlock seedlings was higher than that of planted but not natural amabilis fir. Although differences in 1994 RGR between the clearcut and edge plots were not significant in either species, shoot and root dry weight of planted amabilis fir on the clearcut was much greater than on the edge plot (Table 1). This probably reflected higher irradiance and photosynthetic rates for amabilis fir on the clearcut plot compared to the edge plot once the latter had been eclipsed by shade from the nearby old growth stand (Koppenaar *et al.* 1995).

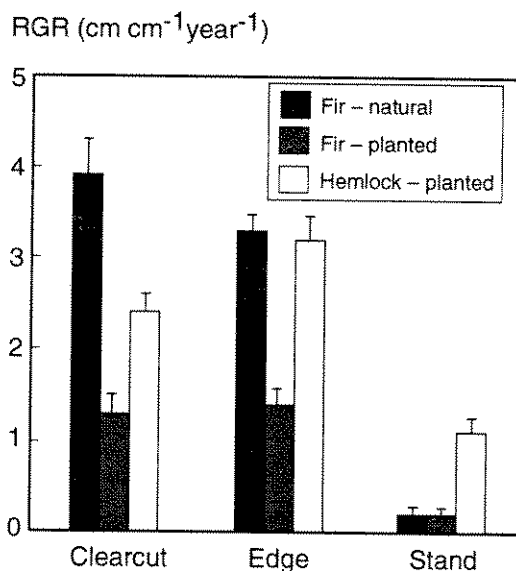


Figure 1. Relative height growth rate (RGR) of amabilis fir and western hemlock.

Table 1. Mean (\pm SE) dry weight and root:shoot ratio of natural and planted amabilis fir

Parameter	Year	Natural			Planted		
		Clearcut	Edge	Stand	Clearcut	Edge	Stand
Shoot dry weight (g)	1993	3.68 (0.43)a ¹	4.36 (0.93)a	1.89 (0.16)b	9.44 (0.80)a	5.75 (0.58)b	5.20 (0.51)b
Root dry weight (g)	1993	1.35 (0.14)a	1.64 (0.35)a	1.44 (0.16)a	3.04 (0.22)a	1.76 (0.23)b	1.51 (0.11)b
Root:shoot ratio (%)	1993	40.77 (3.29)b	43.07 (4.58)b	76.95 (7.63)a	33.68 (1.94)a	30.50 (2.08)a	31.37 (2.17)a

¹ Means followed by different letters indicate significant ($p \leq 0.05$) differences for between plot (within stock) comparisons using Tukey's test.

The root:shoot ratio of natural amabilis fir regeneration was markedly higher than in the planted stock especially considering that root weight of natural regeneration was underestimated due to difficulty in recovering intact root systems (Table 1). The relatively smaller root systems of the planted amabilis fir and the initial confinement of the roots to a small soil volume may have restricted access to available soil nutrients and contributed to their chlorotic appearance. The larger root:shoot ratios of advance regeneration on the stand plot is probably a measurement artifact since these plants were much smaller on average than on the clearcut and edge plots and often displayed severe stem sweep near the soil surface. This made it difficult to determine the location of the root collar and the start of the effective root system. Root systems of natural regeneration in the stand plot were shallow and less fibrous compared to those on the clearcut and edge plots. The second-year RGR of both species was suppressed on the stand plot as a consequence of low understory light levels (Koppelaar *et al.* 1995) and was probably not related to nutrient status.

Foliar Nitrogen

Foliar nitrogen concentrations of first-year (1993) planted amabilis fir (Figure 2) on all plots were below the critical level of 1.15% established for white and red fir by Powers (1983). This N deficiency indicates tissue reserves of N in planted stock were largely depleted or diluted by the end of the first growing season which likely accounts in part for their relatively chlorotic appearance and low RGR in 1994. In contrast, foliar N concentrations in advance amabilis fir on the clearcut and edge plots were above the critical level. While foliar N concentrations of planted amabilis fir in the clearcut plot recovered in 1994, they remained at deficient levels on the edge plot. This suggests that plot microclimate had either a direct effect on N mineralization and availability or an indirect effect on root growth and permeability and thus access to soil N. In the clearcut, larger and more extensive root systems (measured in September 1993) in planted amabilis fir stock may have allowed for increased N uptake on that plot in 1994. Although second-year (1994) height growth of planted amabilis fir did not reflect these plot differences in foliar N concentrations, current-year nutrient effects on growth might be expected the following growing season. Nitrogen concentrations in the small juvenile amabilis fir in this study were generally higher than those reported from other coastal sites in British Columbia and Washington with older and larger amabilis fir trees (Beaton *et al.* 1965, Radwan *et al.* 1989, Weetman *et al.* 1993), and may reflect the dilution of N in those larger trees.

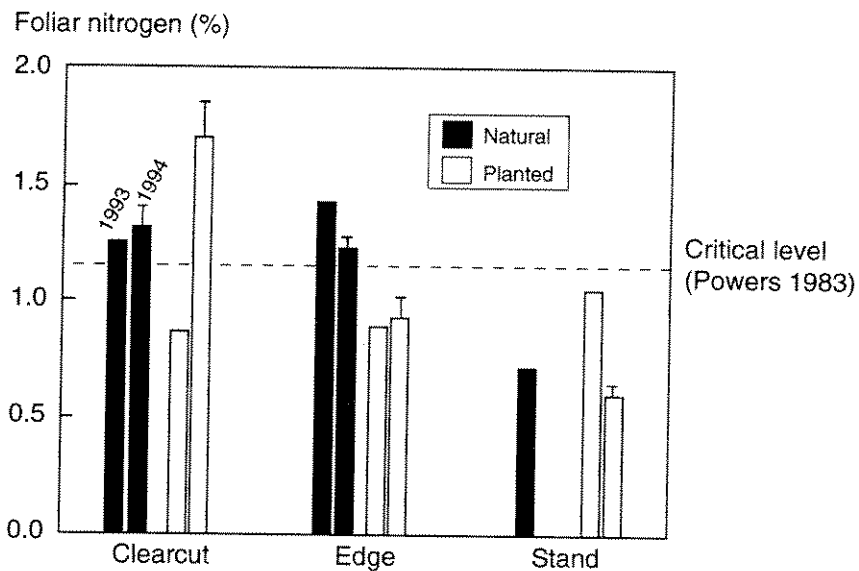


Figure 2. Foliar nitrogen concentrations in natural and planted amabilis fir.

On the stand plot, 1994 foliar N levels in natural and planted amabilis fir were well below those on the edge and clearcut plots indicating a limitation on N availability or acquisition. On the clearcut and edge plots, decomposition rates and availability of N may have increased as a result of stand removal and account for the relatively high foliar N concentrations. In the stand plot, shallow rooting in advance regeneration and root competition from overstory trees may have limited N uptake. In planted stock on the stand, foliar N levels in the second year after planting (1994) declined from levels the previous year. This may reflect depletion of the pre-planting N reserves in the nursery stock down to levels consistent with reduced N uptake in this low light environment.

In the second-year after planting (1994), N concentrations in planted western hemlock (Figure 3) on the clearcut and edge plots were also lower than their natural counterparts and were well below the “adequate” value for hemlock (1.45%) (Ballard and Carter 1986). Foliar N levels of natural hemlock on the clearcut were higher ($p < 0.05$) than those on the edge plot where N may have been slightly deficient, again suggesting that microclimatic conditions on the clearcut plot increased availability of or access to soil N. As with amabilis fir, foliar N levels in natural and planted hemlock plot were lowest on the stand plot.

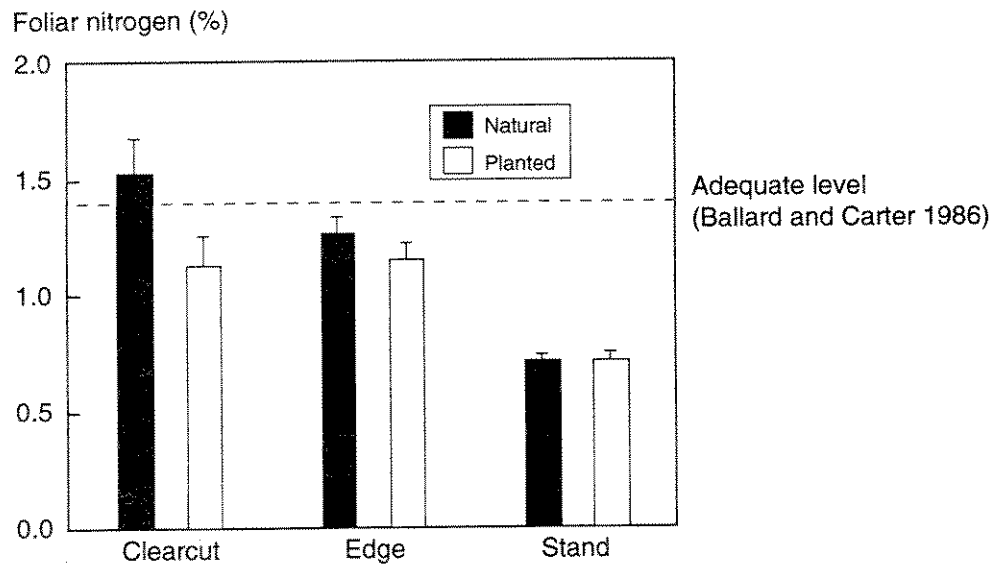


Figure 3. Foliar nitrogen concentration in natural and planted western hemlock.

Conclusions

Natural and planted regeneration on this site contrasted in their nutrient status and this was reflected in differential height growth. Compared to the natural regeneration, which seemed to have acclimated to site N limitations since release in 1989, foliar N concentration of planted stock was in a state of flux two growing seasons after planting in 1993. Nitrogen was apparently limiting growth of planted amabilis fir and western hemlock two years after planting, although foliar N concentrations in planted amabilis fir on the clearcut had recovered to above the critical level in the second year after planting. Natural regeneration of both species generally was not deficient in N five years after release and had greater height growth than their planted counterparts. In planted stock, N deficiency was probably related to insufficient soil penetration by roots or poor contact at the root:soil interface which may have restricted access to available soil N. Larger root:shoot ratios in advance amabilis fir compared to planted stock on the clearcut and edge plots further suggests that natural regeneration was better suited to acquisition of available soil N on this site. Under these nutrient-limited conditions there may be good potential for a fertilizer response in planted or natural shade tolerant montane regeneration (Dunsworth and Arnott, this volume), particularly when root systems are poorly developed or in poor soil contact. The interaction between plot light environment and foliar N concentrations of planted amabilis fir and natural western hemlock favoured regeneration on the most open plot (clearcut) and may be related to carbon allocation, to below-ground growth, or possibly to differential N mineralization rates. Future work will address the interaction between light environment and fertilizer response in natural montane regeneration.

Acknowledgements

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Growth Limitations of Regenerating Montane Conifers in Field Environments

*B.G. Dunsworth
Land Use Planning Advisory Team
Sustainable Forestry Division
MacMillan Bloedel Limited
65 Front Street
Nanaimo, B.C. V9R 5H9*

*J.T. Arnott
Canadian Forest Service
Pacific Forestry Centre
506 West Burnside Road
Victoria, B.C. V8Z 1M5*

Introduction

Montane forests contain a large part of the British Columbia coastal timber harvest for the next 25 years (Smith 1992). Local and global demand to sustain non-timber values has raised concern with clearcut-based silviculture. Coastal forest managers need to know where alternatives to clearcutting are operationally feasible, and economically and ecologically sound. In response to these concerns, a multi-agency cooperative—the Montane Alternative Silvicultural Systems (MASS) Partnership—was established to test new approaches to timber harvesting and subsequent regeneration in the Montane Moist Maritime Coastal Western Hemlock biogeoclimatic variant (CWHmm2) of east Vancouver Island (Green and Klinka 1994). The principal aim of the cooperative is to investigate the biological and economic aspects of alternative silvicultural systems in montane coastal forests. These systems must meet regeneration, aesthetic and wildlife objectives with the greatest economic return, without compromising worker safety. The silvicultural systems being tested are Clearcut, Patch Cut, Green Tree, Shelterwood with a residual Old Growth reserve as the experimental control treatment. These systems are described in detail by Beese (1995).

This study is one of several investigating aspects of regeneration of montane conifers in the MASS project. It focuses on the problem of conifer stagnation in montane forests following clearcut harvesting which may be directly or indirectly related to one or more limiting factors in the regeneration micro-environment (Herring and Etheridge 1976). This stagnation—or more accurately—variable periodic annual growth (Smith 1992) may be related to variable levels of annual photosynthesis (Husted 1982, Keller and Tregunna 1976, Larcher 1983), or to changes in sink strengths that lead to shifts in seasonal biomass allocation or both (Gale and Zeroni 1985, Ledig 1981, Luxmoore 1991, and Stitt and Quick 1989). Thus, the null hypothesis to be tested in this experiment is that photosynthetic conditions are not limiting conifer growth in any of the silvicultural systems being evaluated in the MASS project. A secondary hypothesis being tested is that above-ground growth is more sensitive to environmental stresses than photosynthesis, leading to shifts in biomass allocation.

In order to test these hypotheses, we assumed that the silvicultural systems mentioned above would provide a wide range of light, temperature, evaporative demand, and moisture. Reductions of solar energy input through shade provided by leave trees in some of the systems will cause changes in the soil and air temperature, vapour pressure deficit, light quality and quantity, and patterns of precipitation (Franklin 1963, Kaufmann 1985, Larcher 1983, and Minore *et al.* 1977). Nutrition will be affected by both the microclimatic conditions of each silvicultural system through changes in decomposition rate, nutrient availability and nutrient use from other vegetation (Binkley 1984, Edmonds *et al.* 1989, Harmon and Hua 1991, Vogt 1991, and Vogt *et al.* 1989). However, this is likely to be less dramatic than changes in the photosynthetic environment. Thus, the only remaining factor that we could influence experimentally was edaphic. To assess below-ground resources as a primary limiting factor to seedling growth in any of the silvicultural systems, we conducted fertilization and vegetation removal treatments (Arnott and Burdett 1988, Carlson 1981, Dunsworth 1990, and Dunsworth and DeYoe 1990).

Objectives

Using planted, containerized amabilis fir and western hemlock seedlings, the objectives of this study within each of the silvicultural systems were to determine the:

- impact of light quality and quantity on seedling growth;
- impact of competing vegetation on seedling growth;
- effect of altering soil nutrition on seedling growth;
- degree to which interactions of light, nutrition or vegetative competition affect seedling growth; and
- relationship of light quality and quantity on soil, air temperature and evaporative demand.

Materials and Methods

Silvicultural Systems

These have been described in detail by Beese (1995), and elsewhere in these proceedings.

Microclimatic Measurements

Microclimate was monitored with automated climate stations in each silvicultural system before and, subsequently, after harvesting. Each treatment was instrumented for relative humidity (1.3 m), air temperature (1.3 m, 0.75 m, and 0.25 m), surface temperature and at various depths within the soil (–15 cm, –30 cm and –50 cm), photosynthetically-active radiation (PAR) at 0.75 m, and precipitation with a tipping rain bucket (Figure 1). Each climate station was automated, ran year-round using battery and solar power, and was programmed to provide daily averages, maxima and minima using CR10 data loggers (Campbell Scientific Ltd., Edmonton, Alta.). Each month for a 10-day period, hourly averages for all sensors were sampled. During 1994, data were acquired from January 1, 1994, to November 11, 1994.

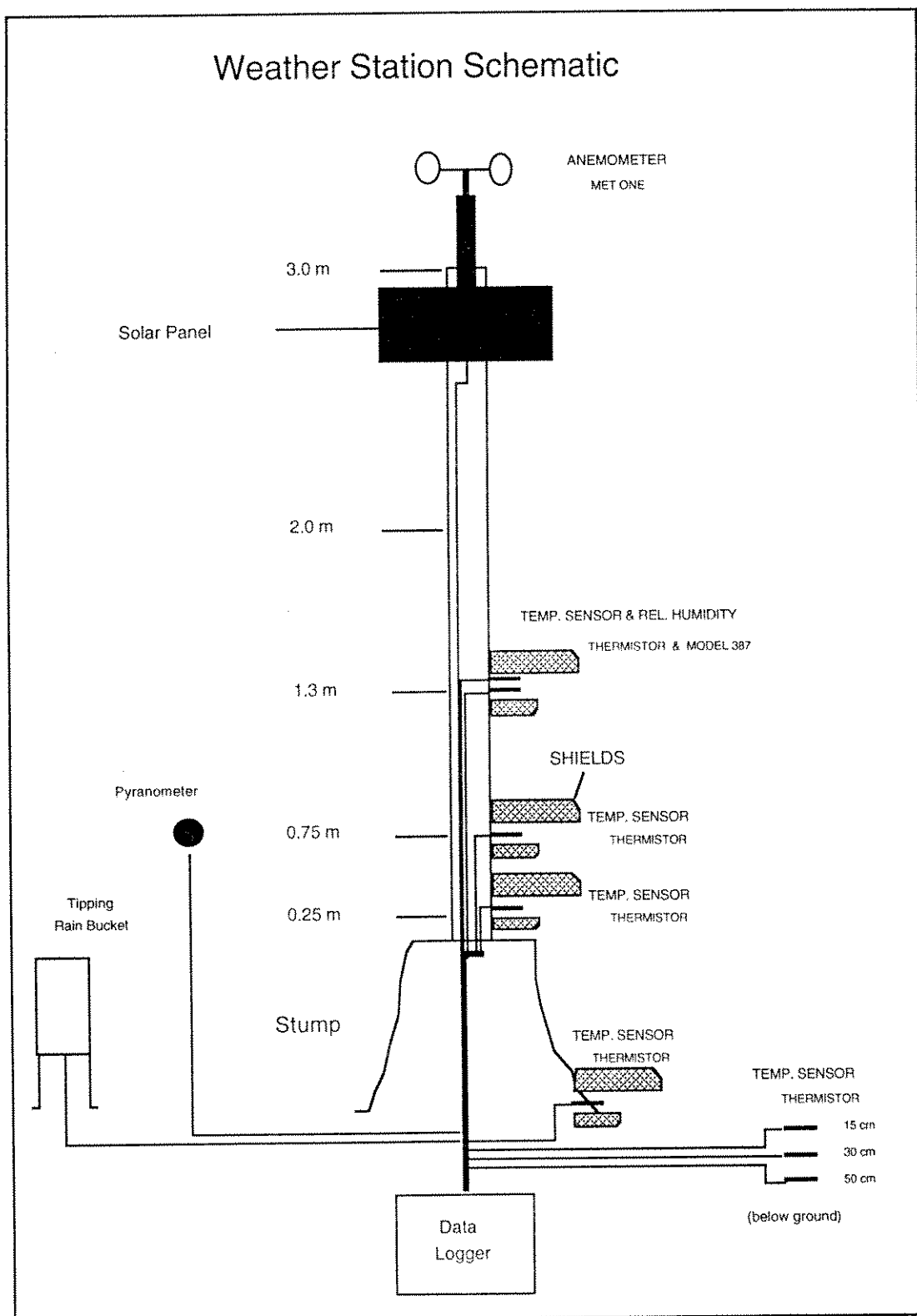


Figure 1. Schematic diagram of one of the climate stations

Regeneration Experiment

Experimental design and plot layout

The study was designed as a split-plot factorial experiment using the five silvicultural systems (Clearcut, Patch Cut, Green Tree, Shelterwood, and Old Growth) as the whole plot. Within each replication of the whole plot, two container-grown tree species, amabilis fir [Ba] (*Abies amabilis* Dougl. ex Forbes) and western hemlock [Hw] (*Tsuga heterophylla* (Raf.) Sarg.), were planted and combined with four, post-planting treatments: control (C), fertilization (F), vegetation removal (H), and vegetation removal with fertilization (FH), and arranged in a factorial experiment. Within each of the replicated whole plots, 12 randomly-selected plots, meeting established planting criteria, were selected within the “core” experimental area of each silvicultural system block using the 30 m × 30 m permanent grid location points. Each plot was divided into four quadrants to which was randomly-assigned one of the four, post-planting treatments (Figure 2). Within each quadrant, three seedlings (measurement units) of each of the two tree species were randomly planted.

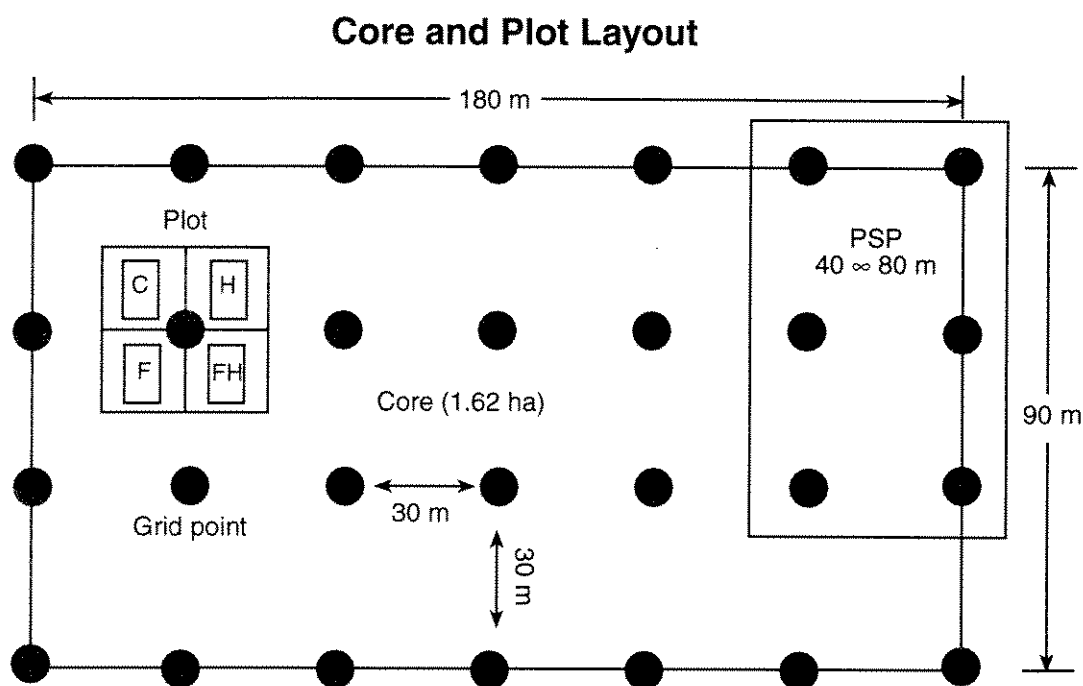


Figure 2. Plot and quadrant layout within plot at one of the core grid points.

Seedling culture and planting

The PSB 415B (Beaver Plastics Ltd., Edmonton, Alta.) plug seedlings were grown using conventional cultural techniques (Van Eerden and Gates 1990) at the Pacific Regeneration Technology Nuuchahnulth Nursery at Port Alberni, B.C., in 1993 and held in cold storage (-2°C) at that company's facility at Campbell River, B.C., until required for planting in early May 1994. Planting took place between May 3 and May 12, and was done using planting “spears” (a blade measuring 24 cm in length and a width tapering from 10 cm at the top to 6 cm at the tip). For those trees in the fertilizer treatments, 24 g of slow-release fertilizer (Nutricote 16-10-10; 180-day formulation) was placed in a speared slot within 10 cm of the tree. A total of 50 trees were sampled from the boxes containing each planted species to characterize:

- a) height, root collar diameter, shoot and root dry weight (mean \pm SD),
- b) root growth capacity (RGC), and
- c) frost hardiness of each species prior to planting (Table 1).

Table 1. *Morphological and physiological characteristics of western hemlock and amabilis fir seedlings at the time of planting*

Species	Height (mm)	Root Collar Dia. (mm)	Shoot Dry Wt. (mg)	Root Dry Wt. (mg)	Shoot/Root Ratio	LT ₅₀	RGC
Western hemlock	247.8 (55.8)	2.86 (0.49)	1729 (782)	957 (549)	2.0 (0.40)	-8.3°C	4.0
Amabilis fir	158.4 (35.4)	2.78 (0.31)	2361 (647)	935 (293)	2.6 (0.38)	-11.6°C	4.0

Means plus standard deviations (in brackets); n = 25, per species.

Post-planting treatment (vegetation control)

Vegetation control was conducted twice on the appropriate post-planting treatment plots during the 1994 growing season. Due to delays in the pesticide application approval process, the first treatment was a mechanical cleaning of the taller vegetation, principally *Vaccinium spp.* and fireweed (*Epilobium angustifolium*) in mid-July. The second treatment was done as planned with the herbicide Glyphosate applied at the rate of 2.34 L/ha in 156 L of water by means of backpack sprayers from August 15 to 19, 1994. The planted trees were temporarily protected from possible drift of the herbicide spray by Kraft paper bags.

Seedling assessment

All planted seedlings were assessed for height (\pm 5 mm), soil surface diameter (\pm 0.5 mm) following planting and at the end of the first growing season (October 11 to 14, 1994).

Data analyses

Differences in seedling growth for main effects and their interactions were assessed using analysis of variance (ANOVA) run in the SAS GLM procedure (SAS Institute Inc. 1992). F-tests for post-planting treatments (T), and their interactions were performed using the random statement in PROC GLM. The effects due to unequal sample sizes (caused by random mortality among all treatment combinations) was taken into account by using the random statement in the SAS GLM procedure. Multiple range testing was done on significant main effects or their two-way interactions using Scheffé's test (Steele and Torrie, 1980).

Results

Seedling Survival

After one growing season, survival of each species was generally in excess of 95%; little mortality occurred among silvicultural systems. Amabilis fir had the poorest survival within the Old Growth silvicultural system at 94%. There was some minor negative effect of fertilization and herbicide treatments on survival of both species.

Seedling Height and Stem Volume Growth

Western hemlock

Silvicultural system and post-planting treatment main effects, and their interactions were significant for seedling height and stem volume at the end of the first growing season (Table 2). The principal cause of these interactions was the very small amount of growth that occurred on seedlings in the Old Growth silvicultural system (Figures 3 and 4). There were no significant differences in height increment among any of the harvested silvicultural systems. The release of additional nitrogen from the Nutricote fertilizer resulted in a significant increase in height and stem volume growth in seedlings growing in all of the silvicultural systems, except the Old Growth. Vegetation removal alone, through mechanical brushing and herbicide application, did not create a significant growth response (Figures 3 and 4).

Table 2. Analyses of variance of western hemlock seedling height and stem volume at the end of the first growing season, and increments of height and stem volume during that period

Source ¹	Df	Mean square	F-value	Pr>F
<i>Height</i>				
S	4	665533	82.33	0.0001
B(S)	10	8083	0.80	0.6312
PLT(S B)	165			
T	3	894247	105.63	0.0001
S*T	12	67251	7.94	0.0001
B*T(S)	30	8465	1.33	0.1090
<i>Height increment</i>				
S	4	690641	76.65	0.0001
B(S)	10	9010	1.47	0.1561
PLT(S B)	165			
T	3	10006625	146.95	0.0001
S*T	12	74740	10.91	0.0001
B*T(S)	30	6849	1.61	0.0193
<i>Stem volume</i>				
S	4	459315099	116.76	0.0001
B(S)	10	3933755	0.73	0.6949
PLT(S B)	165			
T	3	569233609	249.35	0.0001
S*T	12	43262857	18.95	0.0001
B*T(S)	30	2282888	0.74	0.8505
<i>Stem volume increment</i>				
S	4	474946969	108.01	0.0001
B(S)	10	4397288	0.88	0.5541
PLT(S B)	165			
T	3	578340019	241.85	0.0001
S*T	12	43372831	18.14	0.0001
B*T(S)	30	2391311	0.85	0.6945

¹ Source codes: S = silvicultural system B = Block PLT = Plot T = Post-planting treatment

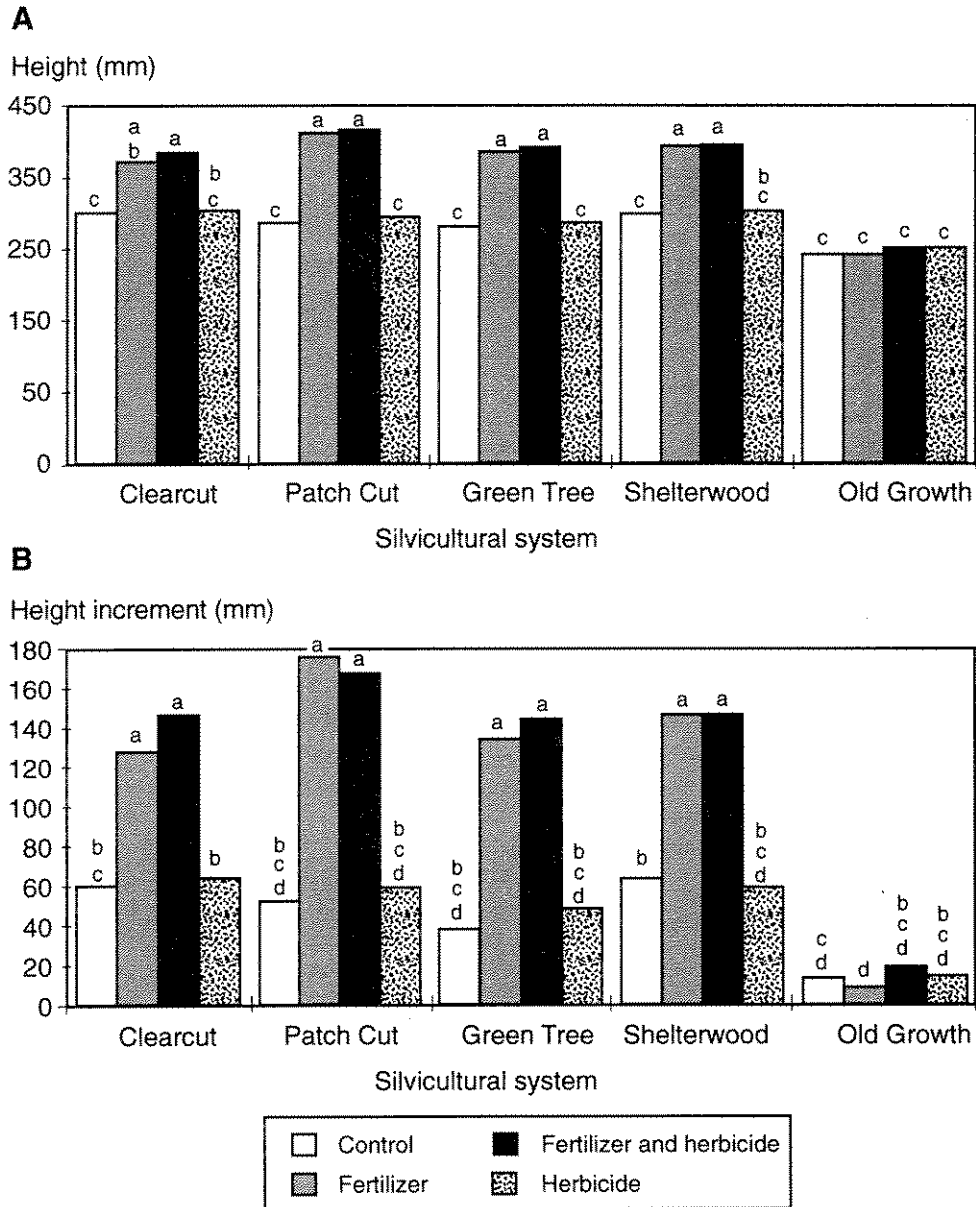


Figure 3. Western hemlock seedling height (A) and height increment (B) after one growing season in each of the four post-planting treatments within each of five silvicultural systems. Reading across each graph, values which share at least one common letter are not significantly different ($p = 0.05$).

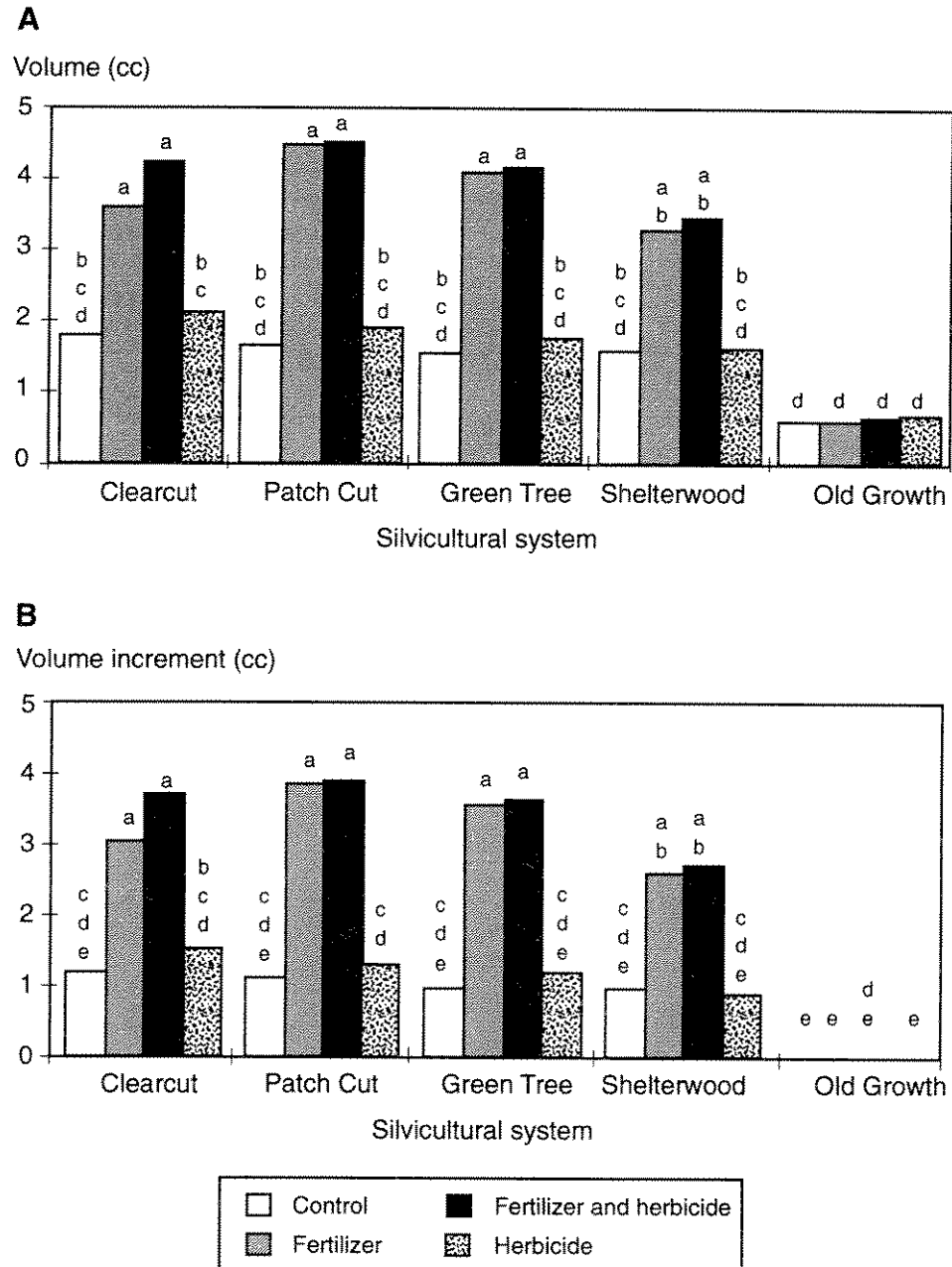


Figure 4. Western hemlock seedling stem volume (A) and stem volume increment (B) after one growing season in each of the four post-planting treatments within each of five silvicultural systems. Reading across each graph, values which share at least one common letter are not significantly different ($p = 0.05$).

Amabilis fir

Silvicultural system and post-planting treatment main effects, and their interactions were significant for seedling height and stem volume at the end of the first growing season (Table 3). Although the growth of the amabilis fir seedlings was less than the western hemlock, the general trends were similar. Again, the Old Growth silvicultural system was the principal cause of interactions among all treatments with very little height and stem volume increment occurring in the Old Growth system

during the first growing season (Figures 5 and 6). Furthermore, fertilization with the Nutricote did significantly increase height and stem volume growth in the seedlings growing in the Clearcut, Patch Cut and Green Tree systems, but not in the others (Shelterwood or Old Growth) where significant or complete canopy cover was retained. Like the hemlock seedlings' response, vegetation removal in the first year had no significant effects on seedling growth.

Table 3. Analyses of variance of amabilis fir seedling height and stem volume at the end of the first growing season, and increments of height and stem volume during that period

Source ¹	Df	Mean Square	F-Value	Pr>F
<i>Height</i>				
S	4	377541	80.66	0.0001
B(S)	10	4680	1.22	0.2792
PLT(S B)	165			
T	3	28046	13.00	0.0001
S*T	12	10819	5.01	0.0002
B*T(S)	30	2157	1.02	0.4331
<i>Height increment</i>				
S	4	382080	76.51	0.0001
B(S)	10	4993	1.78	0.0685
PLT(S B)	165			
T	3	33787	22.84	0.0001
S*T	12	7345	4.96	0.0002
B*T(S)	30	1479	0.92	0.5989
<i>Stem volume</i>				
S	4	78402387	46.65	0.0001
B(S)	10	1680510	1.92	0.0462
PLT(S B)	165			
T	3	26579528	38.73	0.0001
S*T	12	2897807	4.22	0.0007
B*T(S)	30	686198	1.77	0.0061
<i>Stem volume increment</i>				
S	4	75351088	43.32	0.0001
B(S)	10	1780505	2.41	0.0105
PLT(S B)	165			
T	3	27147122	48.67	0.0001
S*T	12	2576271	4.62	0.0003
B*T(S)	30	557725	1.80	0.0052

¹ Source codes: S = silvicultural system B = Block PLT = Plot T = Post-planting treatment

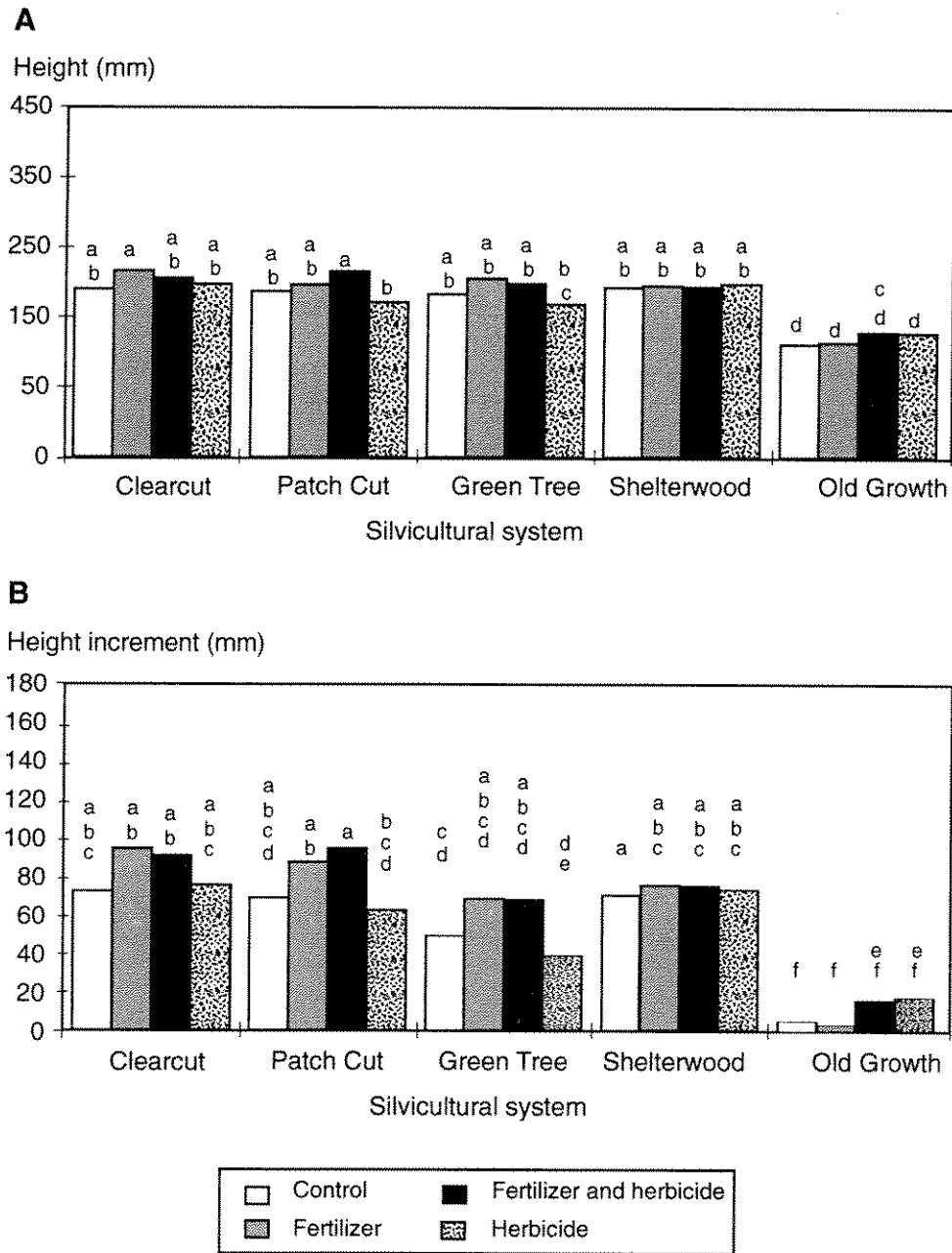


Figure 5. *Amabilis fir* seedling height (A) and height increment (B) after one growing season in each of the four post-planting treatments within each of five silvicultural systems. Reading across each graph, values which share at least one common letter are not significantly different ($p=0.05$).

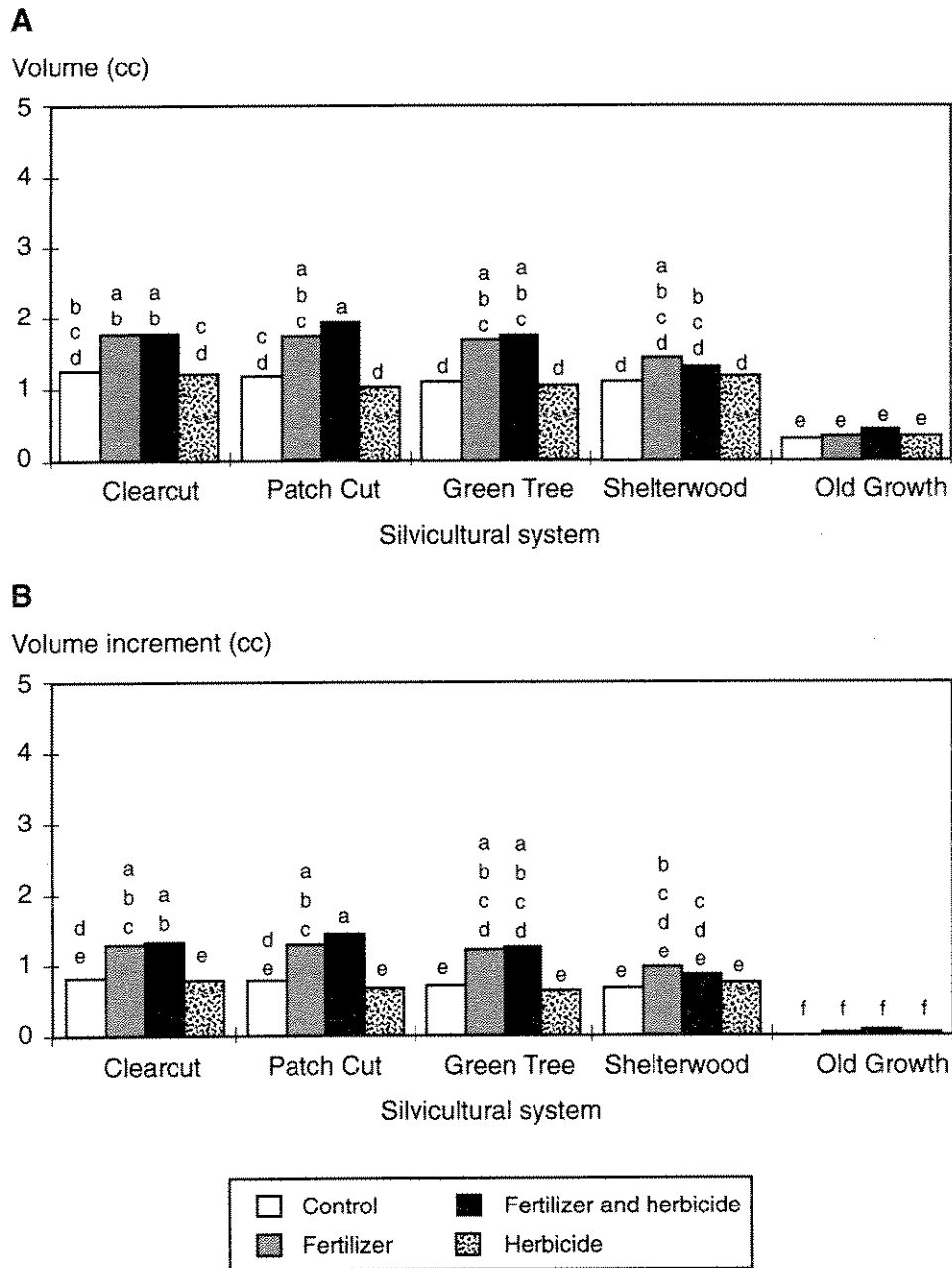


Figure 6. *Amabilis fir* seedling stem volume (A) and stem volume increment (B) after one growing season in each of the four post-planting treatments within each of five silvicultural systems. Reading across each graph, values which share at least one common letter are not significantly different.

Microclimate

During 1994, the climate stations had some sensor problems. The PAR sensor in the Shelterwood had an intermittent malfunction and could not be replaced in time to capture any useable seasonal data. This sensor has been replaced. The surface temperature thermocouple in the Patch Cut had a periodic electrical short which made that data unreliable. All the surface temperature sensors will be changed to the more reliable thermistors in 1995. Finally, the tipping rain gauges broke down in the Clearcut and Patch Cut. The Green Tree was used as the only remaining reliable source of precipitation data for the experiment.

The 1994 seasonal track of daily climate can be broken into four periods (Figure 7):

- January to March, cool spring Julian days 1–90
- April to June, warming trend Julian days 91–181
- July to August, peak heating Julian days 182–243
- September to November, cooling trend with a heat pulse Julian days 244–315

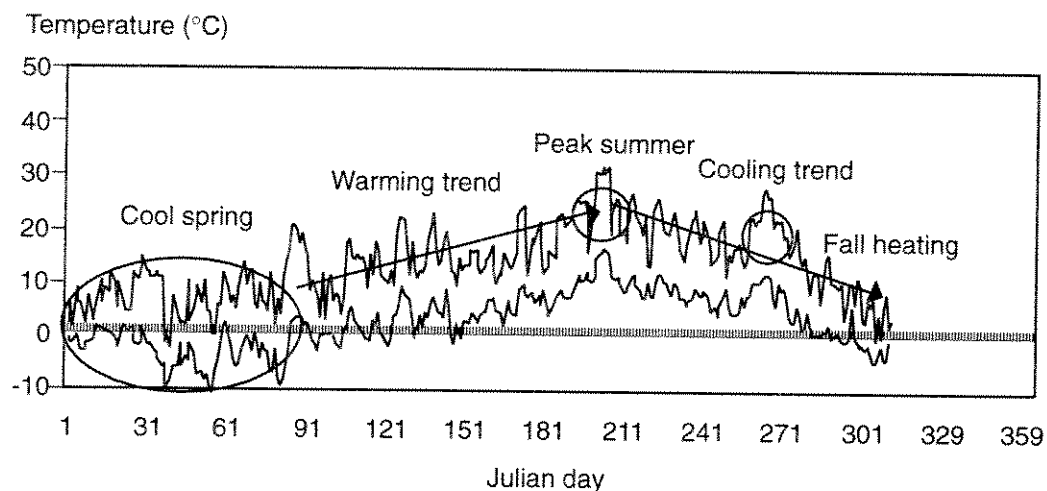


Figure 7. 1994 seasonal pattern of maximum and minimum air temperature (1.3 m) for the clearcut.

Using these periods, we have calculated daily average means for selected sensors to help describe the differences among the silvicultural systems (Table 4). We have also calculated the number of days above given sensor thresholds in order to highlight cumulative events for the same periods (Table 5).

Table 4. Daily average means and standard errors (SE) for different time periods during 1994 with various climate sensors

Time period	Temperature (°C)										Relative humidity (%)	PAR (μE·m ⁻² ·s ⁻¹)	Wind speed (m·s ⁻¹)	Precipitation (mm)	
	Surface					-15 cm									
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE					
Silvicultural system															
Jan-Mar															
Clearcut	0.01	0.03	-0.31	0.18	0.96	0.33	1.07	0.03	85.47	1.34	15.03	1.13	2.03	0.07	-
Patch Cut	- ⁽¹⁾	-	-0.55	0.18	0.77	0.31	1.46	0.03	88.47	1.15	9.24	1.01	1.10	0.03	-
Green Tree	-0.09	0.03	-0.76	0.17	1.11	0.32	0.93	0.02	88.90	1.43	9.15	1.09	1.13	0.04	3.20 0.8
Shelterwood	0.00	0.10	-0.02	0.17	0.44	0.29	1.27	0.05	94.06	1.23	-	-	0.77	0.02	-
Old Growth	0.04	0.04	-0.27	0.12	0.12	0.23	2.03	0.04	97.87	0.79	0.25	0.02	0.51	0.01	-
Apr-June															
Clearcut	9.64	0.44	8.52	0.42	8.36	0.39	7.75	0.34	81.23	1.35	31.55	1.43	2.02	0.06	-
Patch Cut	-	-	8.45	0.42	8.76	0.37	7.63	0.36	80.51	1.21	28.04	1.30	1.08	0.02	-
Green Tree	10.38	0.54	8.58	0.44	8.55	0.39	7.20	0.36	82.66	1.36	27.74	1.27	1.29	0.04	2.69 0.5
Shelterwood	9.17	0.36	8.28	0.39	8.27	0.39	7.68	0.25	86.26	1.39	-	-	0.84	0.02	-
Old Growth	5.96	0.39	6.45	0.38	6.78	0.35	5.20	0.25	94.34	0.85	1.56	0.11	0.48	0.00	-
July-Aug															
Clearcut	17.59	0.46	15.91	0.47	15.53	0.47	13.96	0.17	72.38	1.85	41.30	2.15	1.96	0.05	-
Patch Cut	-	-	15.61	0.45	15.45	0.43	13.42	0.16	73.35	1.67	36.45	1.96	1.20	0.03	-
Green Tree	18.38	0.53	16.08	0.49	15.48	0.45	13.25	0.17	73.88	1.84	36.86	1.93	1.08	0.05	1.81 0.6
Shelterwood	16.15	0.41	15.27	0.44	15.28	0.44	13.17	0.17	76.79	1.83	-	-	0.79	0.02	-
Old Growth	12.88	0.27	13.44	0.36	13.47	0.37	10.76	0.13	87.29	1.31	2.36	0.24	0.47	0.00	-
Sept-Nov															
Clearcut	8.24	0.62	7.57	0.67	7.80	0.66	8.65	0.39	85.47	1.55	20.53	1.37	1.85	0.07	-
Patch Cut	-	-	7.04	0.64	7.52	0.63	8.32	0.37	88.38	1.26	16.23	1.11	1.05	0.02	-
Green Tree	8.88	0.72	7.29	0.66	7.80	0.64	7.76	0.39	87.86	1.56	18.33	1.41	0.88	0.04	3.46 0.7
Shelterwood	7.91	0.62	7.23	0.64	7.38	0.64	8.63	0.39	92.43	1.45	-	-	0.79	0.02	-
Old Growth	7.10	0.49	6.51	0.56	6.41	0.56	8.07	0.28	98.28	0.64	0.33	0.03	0.46	0.00	-

(1) Sensor malfunction; no data available.

Table 5. Numbers of days above given sensor thresholds for various time periods during 1994

Time period	Temperature (°C)							Relative humidity (%)		PAR ($\mu\text{E}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$)	Wind speed ($\text{m}\cdot\text{s}^{-1}$)
	Surface		25 cm		1.3 m		- 15 cm	Max	Min	>30	Max >4
Silvicultural system	Max	Max	Max	Avg	Max	Min	Min	Max	Min	>30	Max >4
Jan-Mar	>30	>40	>30	>4	>30	<-5	>10	>95	<50		
Clearcut	0	0	0	10	0	24	0	70	40	11	47
Patch Cut	— ⁽¹⁾	—	0	8	0	23	0	73	32	7	2
Green Tree	0	0	0	9	0	16	0	70	24	7	14
Shelterwood	0	0	0	7	0	19	0	74	16	—	1
Old Growth	0	0	0	0	0	12	0	86	2	0	0
Apr-June											
Clearcut	0	0	0	79	0	0	11	76	35	45	69
Patch Cut	—	—	0	84	0	0	16	76	50	29	1
Green Tree	18	3	1	82	0	0	11	76	33	28	48
Shelterwood	1	0	0	78	0	0	11	81	29	—	0
Old Growth	0	0	0	73	0	0	0	84	7	0	0
July-Aug											
Clearcut	25	9	6	62	5	0	62	33	40	47	49
Patch Cut	—	—	11	62	5	0	62	37	41	38	3
Green Tree	43	20	15	62	5	0	61	33	35	40	31
Shelterwood	24	0	8	62	6	0	62	44	37	—	0
Old Growth	0	0	0	62	0	0	50	43	16	0	0
Sept-Nov											
Clearcut	5	0	0	51	0	0	30	59	17	20	33
Patch Cut	—	—	2	52	1	0	28	62	20	2	2
Green Tree	19	7	1	51	0	0	13	62	16	12	16
Shelterwood	3	0	3	49	1	0	31	63	18	—	1
Old Growth	0	0	0	47	0	0	16	64	0	0	0

⁽¹⁾ Sensor malfunction; no data available.

Several general observations can be made from the tables. Precipitation and wind speeds were relatively constant across the seasons. Precipitation averaged 2 mm to 3 mm/day by periods, totaling 88.8 cm for the season. Although there was relatively similar rainfall in each period, there was a drying trend during the summer. Drying cycles were not longer than 3 weeks and seldom exceeded one week. The wind speed averaged 1 to 2 m/sec/day for the Clearcut, Patch Cut, and Green Tree and 0.5 to 1 m/sec/day for the Shelterwood and Old Growth. The windiest conditions were found within the Clearcut.

Growing degree days (sum of daily average temperature >4°C at 1.3 m.) were also relatively constant among the silvicultural systems ranging from 2200 to 2300 between January and November (<5% different) (Table 6). The exception was the Old Growth (1846), 25% lower than the rest. The Shelterwood and Clearcut were similar in degree-days and the Green Tree and Patch Cut had the highest values.

Table 6. Growing degree days for silvicultural systems in 1994 (December to November)

Silvicultural System	Growing Degree Days (>4°C)
Clearcut	2290
Patch Cut	2301
Green Tree	2307
Shelterwood	2207
Old Growth	1846

Beyond the general trends, there were several distinctions among the seasons. During the early spring season (January through March) several highlights were evident from the daily data. February was cold and snowy. Most of the below-freezing air temperatures occurred in this period and it was colder in this month than the month before or after (Figure 7). The above-ground temperature gradient (temperatures from the surface to 1.3 m) was steeper for the Clearcut, Patch Cut, and Green Tree than for the Shelterwood or Old Growth (Table 4). Old Growth soils were the warmest and Clearcut soils the coolest during this period, likely an indication of higher radiative loss in the Clearcut. Average PAR levels were 40% lower in the Patch Cut and Green Tree than in the Clearcut, likely a reflection of the effect of sun angle and shading on radiation balance. The Clearcut PAR levels were 60 times higher than the Old Growth. These values are considerably higher than the 10–20 times figure for net radiation suggested by Fowler and Anderson (1987) for a sunny summer day at high elevation in the Pacific Northwest.

During the spring and summer (April through August) the dominant climate event was warming (Figures 8 and 9). The most distinctive silvicultural system difference was an approximate 30-day lag in the start of the warming trend for the Old Growth (Figures 7 and 10). This resulted in a reduction of 2°C/day in the daily average Old Growth temperature (1.3 m) for both the April through June and the July through August periods (Table 4). The same lag was evident in the soil temperature averages (15 cm) with a 2°C to 2.5°C reduction in the Old Growth that persisted through the summer. During the same period, PAR levels for all treatments were similar with the obvious exception of the Old Growth. The Clearcut had PAR levels 30 times higher than Old Growth during this period (Table 4) (Figures 11 and 12).

Another dominant climate event related to warming during the spring and summer was surface temperatures. Surface temperature maximums were approximately 20°C greater in the Clearcut than the Old Growth. This is within the range observed by Holbo and Childs (1987) and Spittlehouse and Stathers (1990). Surface temperatures were highest in the Green Tree (note the Patch Cut sensor was inoperative). The Green Tree had 61 days with maximum surface temperatures >30°C and 23 days >40°C (Table 5). The Clearcut had considerably less at 25 days >30°C and 9 days >40°C. This may be due to a combination of lower winds and higher slash loads in the Green Tree concentrating heat near the surface.

The fall cooling trend was punctuated by a warm period in September which lasted for three weeks. During this period, the Green Tree surface temperatures jumped to near summer levels (data not shown). The Green Tree was the only silvicultural system with surface maximums >40°C and had four times as many surface maximum days >30°C (19) than the Clearcut, likely due to low wind speed and reduced cooling (Table 5). The PAR levels for all silvicultural systems dropped to approximately 50% of the July/August levels and the Old Growth lag in air and soil temperature averages was eliminated. The latter was likely due to lower relative radiative heat loss in the Old Growth.

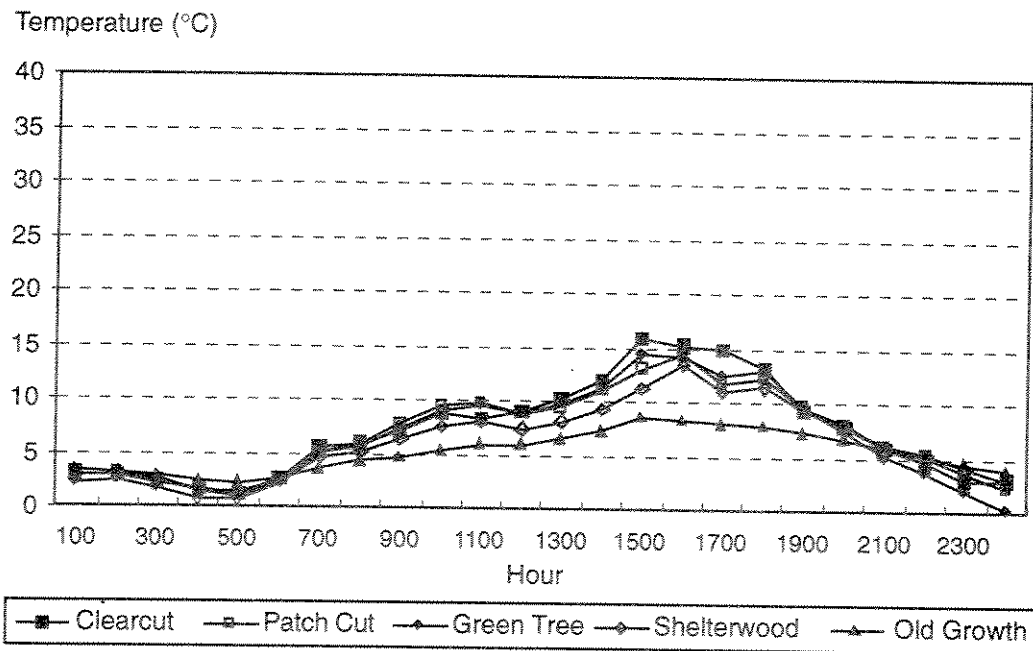


Figure 8. Diurnal pattern for 25 cm air temperature among the silvicultural systems May 30, 1994.

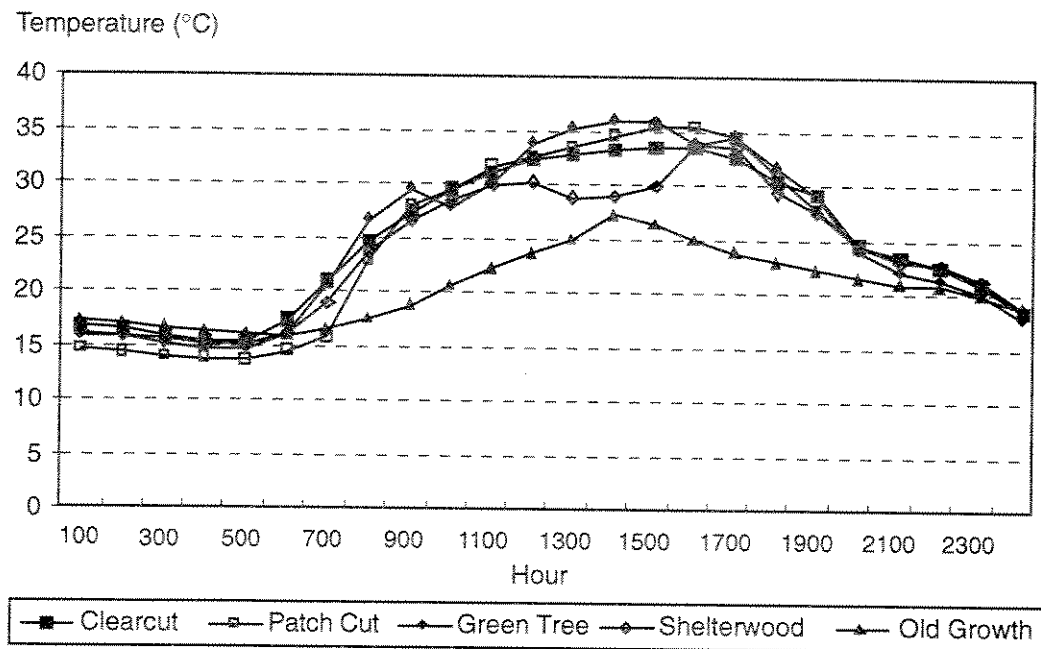


Figure 9. Diurnal pattern for 25 cm air temperature among the silvicultural systems July 24, 1995.

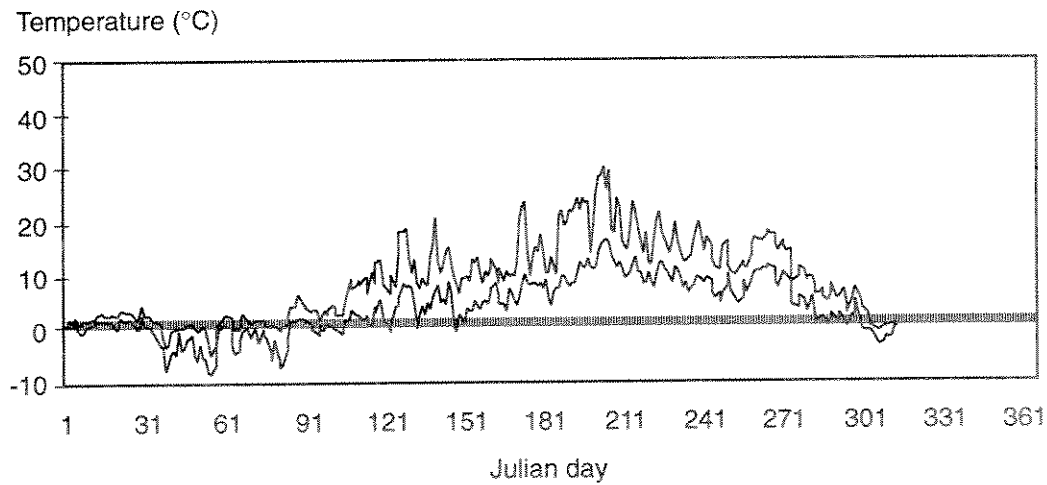


Figure 10. 1994 seasonal pattern of maximum and minimum air temperature (1.3 m) for the Old Growth.

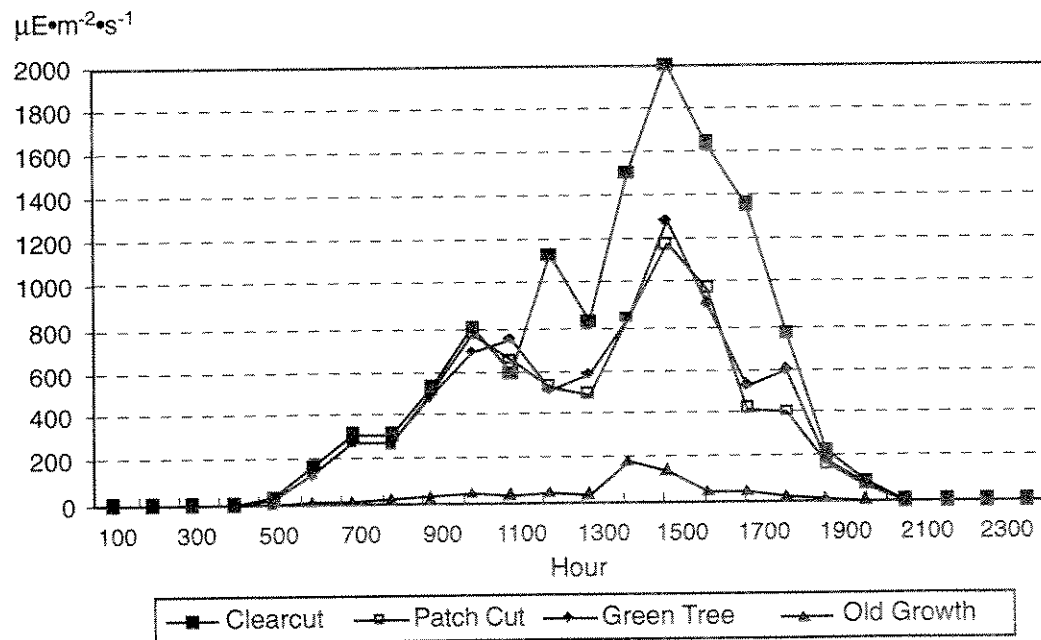


Figure 11. Diurnal pattern for photosynthetically active radiation among the silvicultural systems May 30, 1994.

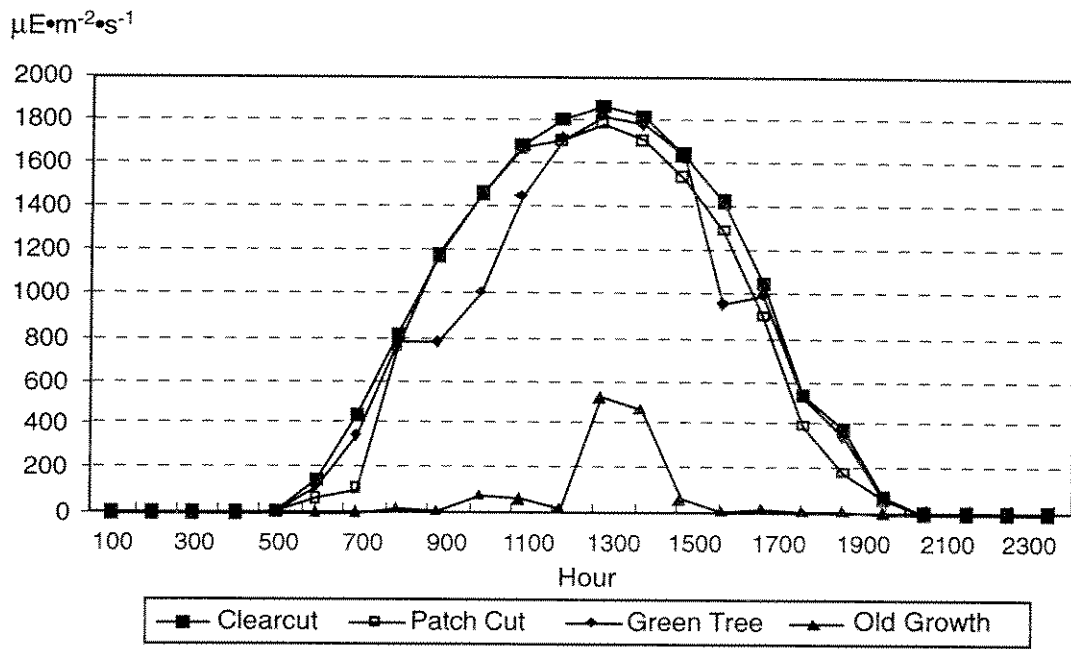


Figure 12. Diurnal pattern for photosynthetically active radiation among the silvicultural systems July 24, 1994.

Discussion

The microclimate record for the MASS study in 1994 is similar to other studies in the Coastal Western Hemlock biogeoclimatic zone on Vancouver Island in recent times (Livingstone and Black 1986, Dunsworth 1992). Both these studies indicate a typical coastal season with spring warming cycles beginning in March, peaking in July and again in September. Both studies also indicated periodic droughts during July through September, with drought intervals as long as four weeks. These studies had lower levels of total precipitation (ranging from 40 cm to 77 cm), but only recorded May to November conditions.

The growing degree-day similarities between Clearcut and Shelterwood in our experiment are likely an artifact of the degree-day calculation. Both Clearcut and Shelterwood treatments tended to be generally cooler than Patch Cut or Green Tree, but for different reasons. The Clearcut was likely due to more wind associated with a longer fetch and the Shelterwood to a shading effect from the remaining overstory. Both the Green Tree and Patch Cut areas tended to be protected by trees in adjacent treatments or leavestrips. This tended to trap heat and increase daily averages.

The most interesting observation in the first season of this experiment is that nutrition is far more limiting than any of the microclimate differences created by various levels of canopy removal. Light and temperature differences were marked among canopy removal treatments, with shifts in the duration, intensity, and timing of stress events. However, growing degree-day differences were minor (<5%) and combined with short drying cycles have kept the seasonal microclimatic stress relatively low and treatment differences slight. The only significant influence of microclimate during the first growing season was in the Old Growth where the markedly low light levels significantly reduced seedling growth. Inability to conduct photosynthesis during a significant portion of the growing season has reduced the opportunity for a fertilizer response to express itself in these Old Growth seedlings. These plants are likely reallocating carbon and changing leaf architecture to favour shade needles, a higher long-term priority than shoot elongation (Bazzaz *et al.* 1987).

The fertilizer response is likely due to a shortage of nitrogen associated with high accumulations of organic matter and low levels of organic decomposition (Hinckley *et al.* 1981). This, combined with newly planted seedlings and limited soil volume, has resulted in a significant response by both species to slow release fertilizer near the planting hole. The western hemlock fertilizer response is not unusual (and could be anticipated for amabilis fir). Similar responses have been documented previously in the Coastal Western Hemlock zone on Vancouver Island for planted hemlock seedlings by several investigators (Carlson 1981, Arnott and Burdett 1988, and Nuzdorfer 1987). The difference in the response between amabilis fir and western hemlock may be related to:

- amabilis fir having a lower relative photosynthesis associated with lower stress tolerance than western hemlock (Brix 1981, Hinckley *et al.* 1981, Livingstone and Black 1988, and Puritch 1973), or
- amabilis fir having a stronger shift in biomass allocation to roots than hemlock (Ledig 1983, Livingstone and Black 1988, Sood and Singh 1984), or
- a combination of both.

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Montane Alternative Silviculture Systems: Ecophysiology of Regenerating Conifers

A.K. Mitchell and J.T. Arnott
Canadian Forest Service
Pacific Forestry Centre
506 W. Burnside Road
Victoria, B.C. V8Z 1M5

Abstract

Coastal montane forests are becoming increasingly important sources of fiber supply in British Columbia. These high elevation sites are subject to harsh climatic conditions and short growing seasons that may reduce regeneration performance below expectations. Silvicultural alternatives to clearcutting that employ varying levels of overstory removal may provide means by which to mitigate these environmental extremes. In this study, physiological and morphological characteristics of *Abies amabilis* (Ba) and *Tsuga heterophylla* (Hw) planted under different silviculture systems treatments (CC, Clearcut; PC, Patch Cut; GT, Green Tree Retention; SW, Shelterwood; OG, Old Growth) were measured to compare acclimation of the two species to different overstory removal regimes. Physiological characteristics (net photosynthesis and chlorophyll fluorescence) were more responsive to the silviculture systems treatments than morphological ones (height growth, specific leaf area) but effects were small and inconsistent. Evidence of acclimation appeared first in chlorophyll fluorescence (Fo) in July and later in net photosynthesis in September. After one year, height growth and specific leaf area were not significantly affected by the treatments except in the old growth where light levels were extremely low. Western hemlock had greater acclimation to the treatments than amabilis fir but this did not confer a growth advantage.

Introduction

The problem of conifer stagnation in montane ecosystems following harvesting may be directly or indirectly related to one or more limiting factors in the regeneration microenvironment (Herring and Etheridge 1976). The use of alternative silvicultural systems to clearcutting that employ varying levels of overstory removal may produce shade levels sufficient to reduce light and temperature (Tucker and Emmingham 1977) to the extent that growth stagnation may be more severe or more frequent. This may limit the effectiveness of using natural and advance regeneration for restocking (Herring and Etheridge 1976) and necessitate artificial regeneration.

The success of artificial regeneration on montane sites harvested using Clearcutting, Patch Cutting, Shelterwood, or Green Tree Retention, will depend on the extent to which such treatments impose stress on seedlings (Franklin 1963). For example, exposure may reduce growth by photoinhibition of photosynthesis (Powles 1984) and shade may decrease carbon uptake (Emmingham and Waring 1973). Potential shifts in carbon allocation from roots to shoots (Hilbert *et al.* 1991), particularly in shade-tolerant amabilis fir (*Abies amabilis*; Ba) and western hemlock (*Tsuga heterophylla*; Hw), may threaten survival during seasonal periods of water stress (Puritch 1973, Brix 1979). Regeneration success will also depend on how nitrogen (N) nutrition interacts with shade to modify growth (Hilbert *et al.* 1991) in these shade-tolerant species, particularly on montane sites with thick litter layers (Knapp and Smith 1982) or vigorous competing vegetation.

Acclimation to stresses may provide mechanisms by which shade tolerant trees can maintain growth rates in low-light environments. For example, adjustments in foliar morphology have been

observed in response to clearcutting in understory amabilis fir (Tucker *et al.* 1987) and residual western hemlock after clear and shelterwood cutting (Tucker and Emmingham 1977). Adjustments in foliar physiology have also been observed. For example, exposure reduced photosynthesis and altered water use of western hemlock in different habitats (Keller and Treguna 1976) and seasonal adjustments in photosynthesis, respiration, transpiration and water relations were found in four *Abies* species including amabilis fir (Puritch 1973, Teskey *et al.* 1984). There are also indications that photosynthesis in different understory species can be influenced to varying degrees by shade (Knapp and Smith 1982).

Growth reductions resulting from the effects of overstory shading on photosynthesis may differ with site quality. In amabilis fir, growth rates and foliar nutrient concentrations were correlated (Radwan *et al.* 1989). On good sites, or in response to fertilization on poor sites, growth may be stimulated in low light environments as a result of increases in foliar efficiency of photosynthesis or foliar biomass (Brix 1971, Brix 1983) and promote successful artificial regeneration of sites harvested using alternative silvicultural systems to clearcutting.

Potential problems in the regeneration of Montane stands have led to the formation of the Montane Alternative Silviculture Systems (MASS) partnership to investigate different harvesting intensities and silvicultural strategies. An operational trial was established at Iron River on Vancouver Island in 1993 and several investigations are under way into limits to regeneration on the site. In this study, physiological and morphological characteristics of *Abies amabilis* and *Tsuga heterophylla* planted under different silviculture systems treatments were compared. Measurements were taken twice during the first growing season (July and September) to study the impact of the different treatments on the functional and structural acclimation of these two shade-tolerant montane conifers.

Methods and Measures

Silvicultural Systems

Harvesting was completed (fall 1993) in a replicated treatment matrix (3 replicates) that includes three silvicultural alternatives: Patch Cuts (PC), Shelterwood (SW), and Green Tree Retention (GT). These are compared with Old Growth (OG) and Clearcut (CC) controls. The site is located on Vancouver Island at Iron River in the montane variant of the Moist Maritime Coastal Western Hemlock subzone (740–850 m). Pre-treatment ecological surveys are complete and instrumentation is in place to monitor climatic conditions on the site. Silvicultural treatments are described in detail by Beese in these proceedings. A summary is included here for reference. Old Growth: a 20 ha reserve of multi-storied uneven-aged old growth forest dominated by amabilis fir, western hemlock, red cedar and yellow cypress. Clearcut: a 69 ha conventional clearcut (1993/1994). Patch Cut: three 1.5 ha openings within each of the 9 ha treatment blocks. Green Tree: a clearcut with 25 trees/ha left within each 9 ha treatment block selected to be representative of the stand structure before harvesting. Shelterwood: approximately 30% of the original stand basal area retained within each 9 ha treatment block representative of the stand structure prior to harvesting.

Plot Establishment

Amabilis fir and western hemlock seedlings were planted in one replicate of each of the silvicultural systems treatments (SW2, PC2, GT2) Old Growth (OG1) and a Clearcut (CC1) and adjacent to regeneration plots in treatment blocks instrumented with climate stations (Arnott and Dunsworth, this volume).

Within each of the treatment blocks, 6 plots were chosen randomly and planted with three sub-plots. Each sub-plot had 12 trees of each species for a total of 72 in each of the 5 silvicultural treatments. These plots were established using identical container stock (1-0 PSB 415B amabilis fir and western hemlock) and seed sources as were used in adjacent silvicultural trials (Arnott and Dunsworth, this volume).

To monitor soil water status, neutron probe access tubes were installed at four randomly selected plots (of the 6) in each treatment block (total, 20 tubes). The tubes allow measurements at 10, 20, 30 and 50 cm below the surface.

Seedling Morphology and Physiology

In the field, height measurements were taken in July and September on all seedlings of each species in each treatment. Foliage samples were also collected to determine specific leaf area (cm^2/gm) and foliar nitrogen concentrations on 6 bulk samples of each of the species (one from each of the 6 plots) in each silvicultural systems treatment block.

In July and September, photosynthesis (ADC-LCA2; Analytical Development Company, Hoddesdon, England) and chlorophyll fluorescence (CF-1000; P.K. Morgan, Andover, MA) were measured on 6 trees of each species taken from the 6 plots in each treatment block. Photosynthesis was measured at high light intensity ($1200 \mu\text{mol}/\text{m}^2/\text{s}$ photosynthetically active radiation; PAR) and at ambient temperature (20 to 25°C) and vapour pressure difference (1.64 kPa). Chlorophyll fluorescence measurements were conducted under ambient conditions (25°C). After these measurements, tree water potential was determined using a pressure chamber. Water potentials were related to neutron probe (Campbell Pacific Nuclear Corp., Martinez, California) measurements of soil moisture (volumetric water content; percent) at 10, 20, 30 and 50 cm depths.

Data analysis

Physiological and morphological parameters were analysed using a nested design with sub-plots and species nested within treatment blocks. Silvicultural treatments were compared using ANOVA (SAS Institute) and where significant effects were found, multiple range tests were conducted using Duncan's multiple range test (Zar 1984).

Results

Chlorophyll fluorescence (F_o) in July in amabilis fir was significantly greater than in western hemlock in Clearcut (CC), Patch Cut (PC) and Green Tree (GT) treatments but not in Shelterwood (SW) or Old Growth (OG) (Figure 1, Appendix 1A). Among the treatments, only the Shelterwood (SW) was significantly different than the other treatments, chlorophyll fluorescence being greater there in both species. This treatment effect continued into September but interspecific differences disappeared (Figure 1, Appendix 1A).

Photosynthesis rates in July were not significantly different between the species or among the silviculture systems treatments (Figure 2, Appendix 1B). In September, photosynthesis rates under high light levels were similar in both species except in the Green Tree (GT) where amabilis fir had significantly lower rates than western hemlock (Figure 2, Appendix 1B).

Soil moisture status at 10 cm below the surface remained virtually constant throughout the growing season (May to September) and there were no significant differences among the silviculture systems treatments (Figure 3, Appendix 1C). Mid-day tree water potentials (Figure 4, Appendix 1D) were significantly lower in both species in the Clearcut (CC) and in western hemlock in the Green Tree (GT) and Shelterwood (SW) in July but not in September.

Height growth (Figure 5, Appendix 1E) was not significantly different among the silviculture systems treatments except in the Old Growth (OG) where height growth was less. Between the species, amabilis fir had greater height growth than western hemlock only in the Patch Cut (PC) but the difference was small (1.5 cm). Specific leaf area (Figure 6, Appendix 1F) was not affected by the silviculture systems treatments. Only in the Old Growth was it significantly higher than in the other treatments. Western hemlock had significantly greater specific leaf areas than amabilis fir in all the silviculture systems treatments.

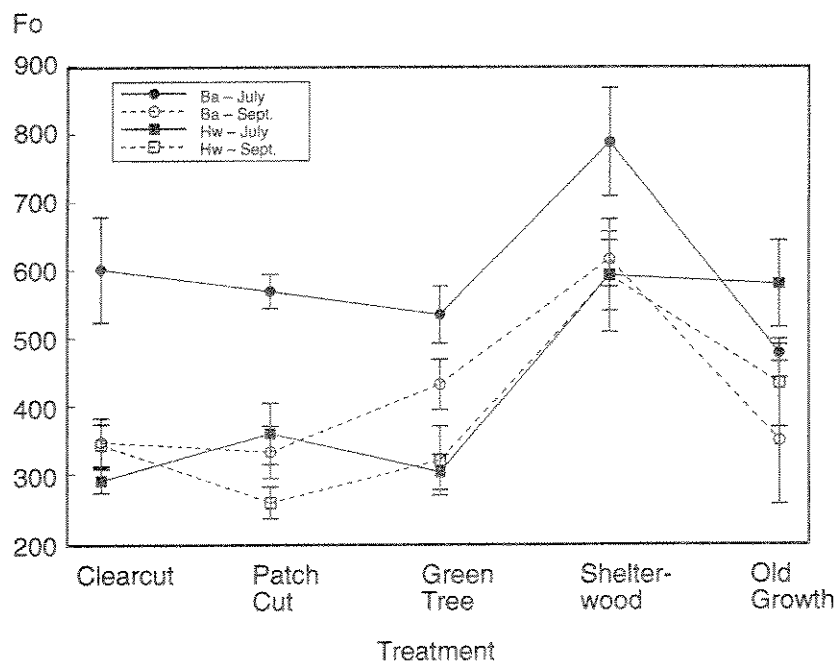


Figure 1. Chlorophyll fluorescence (F_o , initial fluorescence) in July and September in *Abies amabilis* (Ba) and *Tsuga heterophylla* (Hw) planted under different silviculture systems treatments.

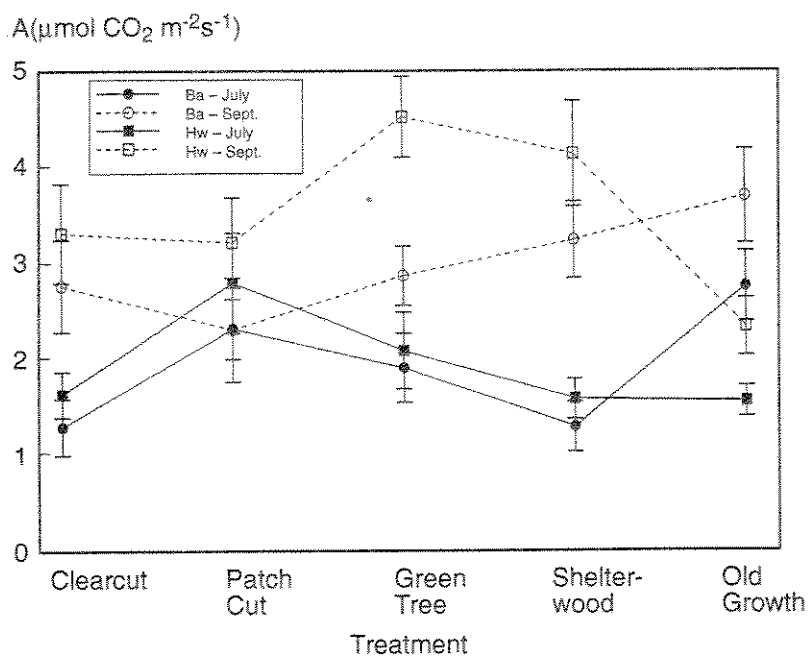


Figure 2. Net photosynthesis ($\mu\text{molCO}_2/\text{m}^2/\text{s}$) at high light intensity ($1200 \mu\text{mol}/\text{m}^2/\text{s}$ PAR) in July and September in *Abies amabilis* (Ba) and *Tsuga heterophylla* (Hw) planted under different silviculture systems treatments.

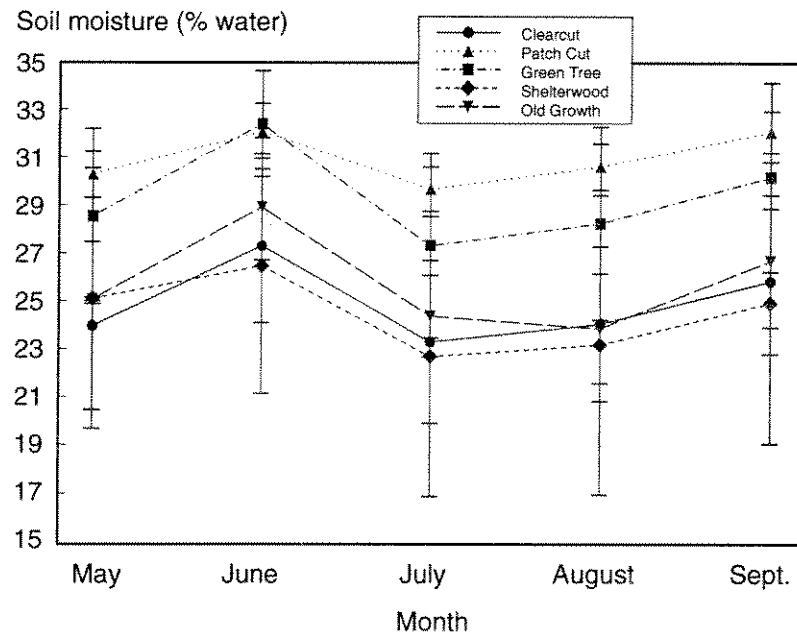


Figure 3. Seasonal changes in soil moisture status (% moisture) at 10 cm depth under different silviculture systems treatments.

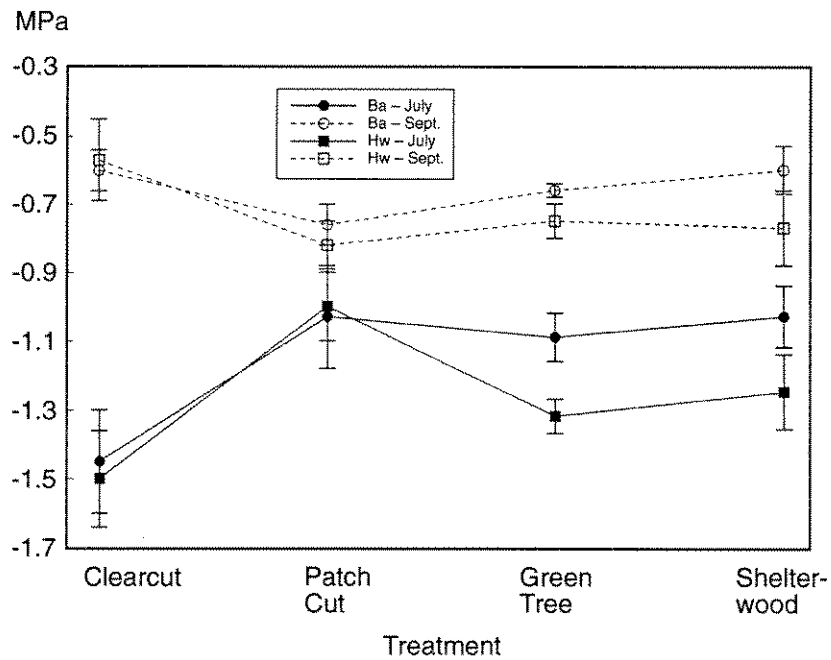


Figure 4. Tree water stress (MPa) in July and September in *Abies amabilis* (Ba) and *Tsuga heterophylla* (Hw) planted under different silviculture systems treatments.

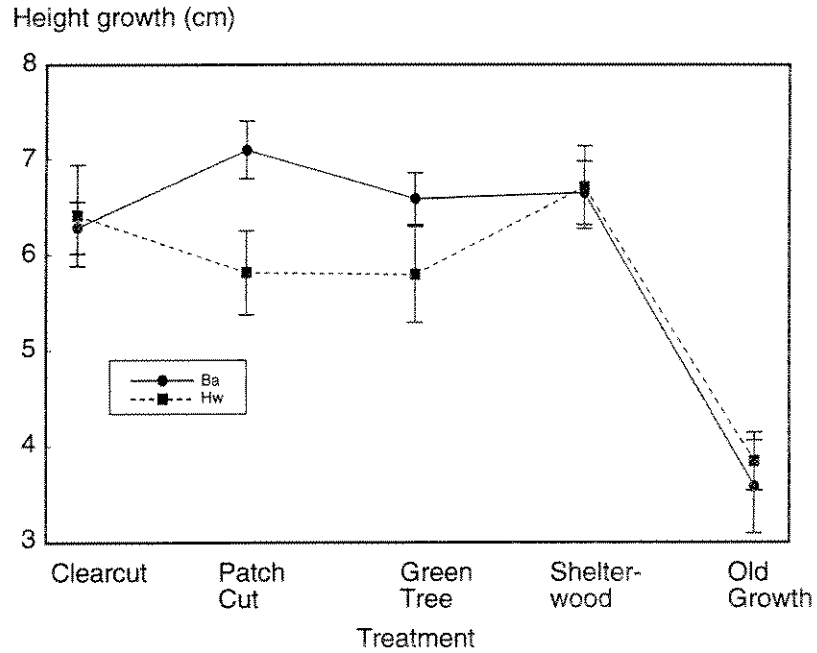


Figure 5. Height growth (cm) of *Abies amabilis* (Ba) and *Tsuga heterophylla* (Hw) planted under different silviculture systems treatments.

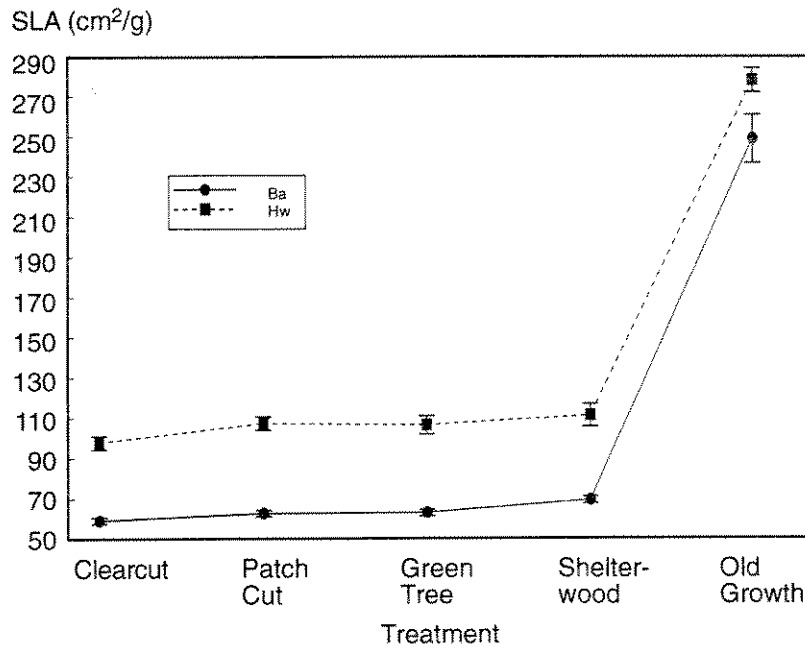


Figure 6. Specific leaf area (cm²/g) of *Abies amabilis* (Ba) and *Tsuga heterophylla* (Hw) planted under different silviculture systems treatments.

Discussion

In the first growing season after spring planting, acclimation to the different silviculture systems treatments was evident to a limited extent in seedling physiology but not morphology. The two species reacted to differing degrees, with western hemlock being generally more responsive than amabilis fir as was found in a nursery experiment in which shade was used to induce acclimation (Mitchell and Arnott 1995). The most striking contrasts, particularly in morphology, were found between the Old Growth, where light levels were very low (less than 50 $\mu\text{mol}/\text{m}^2/\text{s}$ PAR), and the other treatments.

Effects on chlorophyll fluorescence (F_o) under the different treatments became apparent as soon as the seedlings produced new shoots. Prior to that (in May), there were no significant differences among the treatments—probably because of the uniform nursery stock that was used for planting (Arnott and Dunsworth, this volume). Initial chlorophyll fluorescence (F_o) has been used as an indicator of the amount of chlorophyll *a* in the foliage and rises drastically with damage to that photosystem II pigment (Krause and Weis 1984, 1991). By July in the Shelterwood, a greater F_o than in the other treatments may indicate photooxidation of chlorophyll *a* and result from daily transitions between shade and bright sun. The new shoots of amabilis fir were apparently more sensitive to damage than western hemlock (July) but differences between the species disappeared by September, indicating the seedlings could repair photodamage (Gillies and Vidaver 1990) and that F_o was probably also influenced by the stage of foliage development. This is consistent with seasonal changes in chlorophyll concentration in a variety of conifers (Lewandowska and Jarvis 1977, Köstner *et al.* 1990) and their effects on fluorescence (Lichtenthaler *et al.* 1989).

Indications of photooxidation and photoinhibition arising from the chlorophyll fluorescence data were supported by visual symptoms of bleaching; however, this was not apparent in photosynthesis rates at 1200 $\mu\text{mol}/\text{m}^2/\text{s}$ PAR. Photooxidative bleaching does not always cause inhibition of photosynthesis but plants grown in the shade often react immediately to high PAR with reduced photosynthetic rates (Powles 1984). In this study, photosynthesis rates were similar across treatments and between species in July but by September differences began to appear. This may have resulted from declining foliar nutrient concentrations over the course of the season that resulted in reduced chlorophyll *a* (Lewandowska and Jarvis 1977) and photosynthetic efficiency (Brix 1981).

The silvicultural treatments did not differ with respect to seasonal water deficits. Water stress can influence chlorophyll fluorescence and photosynthesis in conifer seedlings (Conroy *et al.* 1986, Toivonen and Vidaver 1988) but in this study, soil moisture status in the rooting zone (top 10 cm) remained high (23 to 31% volumetric water content) throughout the season. Tree water stress levels (-1.5 MPa) were well below thresholds defined for reductions in photosynthesis in conifer seedlings including amabilis fir (Puritch 1973) and western hemlock (Brix 1979). As a result, physiological differences in photosynthesis and chlorophyll fluorescence among treatments could not be attributed to water stress.

Despite indications of acclimation to the silviculture systems treatments, first in chlorophyll fluorescence in July and later in photosynthesis in September, there were no significant effects on growth. This may at least in part be a carry-over effect of nursery culture (preformed buds and adequate foliar nutrients) and indicate that the silviculture systems treatments were not sufficiently different with respect to the above-ground light environment to induce changes in morphology. In a laboratory experiment, 60% shade was required to induce significant acclimation in western hemlock and amabilis fir seedlings (Mitchell and Arnott 1995). Previous studies have shown that specific leaf area is a sensitive indicator of the light environment in which shoots develop (Tucker *et al.* 1987). In this study, specific leaf area was also unaffected, a further indication that the light levels were not sufficiently different among the treatments to induce morphological differences in the seedlings. Only in the Old Growth, where shade levels were between 90 and 95% of full sun, was there a significant decrease in seedling height growth and increase in specific leaf area.

Acknowledgements

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Appendix 1: Statistical analyses

A. Chlorophyll fluorescence (Fo):

Month	Species ²	Silviculture systems treatments ¹				
		CC	PC	GT	SW	OG
July	Ba	b	b	b	a	b ³
		A	A	A	A	A ⁴
	Hw	b	b	b	a	b
		A	B	B	A	A
September	Ba	b	b	b	a	b
		A	A	A	A	A
	Hw	b	c	bc	a	b
		A	A	A	A	A

¹ Silviculture systems treatments abbreviations:
CC, Clearcut; PC, Patch Cut; GT, Green Tree; SW, Shelterwood; OG, Old Growth

² Species abbreviations: Ba, amabilis fir; Hw, western hemlock

³ Multiple range test among treatments ($p \leq 0.05$)

⁴ Multiple range test between species within months ($p \leq 0.05$)

B. Net photosynthesis (1200 $\mu\text{mol}/\text{m}^2/\text{s}$ PAR):

Month	Species ²	Silviculture systems treatments ¹				
		CC	PC	GT	SW	OG
July	Ba	b	a	ab	b	b ³
		A	A	A	A	A ⁴
	Hw	b	a	ab	b	b
		A	B	A	A	B
September	Ba	a	a	a	a	a
		A	A	A	A	A
	Hw	ab	ab	a	a	b
		A	A	B	A	A

¹ Silviculture systems treatments abbreviations:
CC, Clearcut; PC, Patch Cut; GT, Green Tree; SW, Shelterwood; OG, Old Growth

² Species abbreviations: Ba, amabilis fir; Hw, western hemlock

³ Multiple range test among treatments ($p \leq 0.05$)

⁴ Multiple range test between species within months ($p \leq 0.05$)

C. Soil moisture (% by volume):

Seasonal	May	Jun	Jul	Aug	Sep
	a	a	a	a	a ¹
Treatments ²	CC3	PC	GT	SW	OG
	a	a	a	a	a ³

¹ Multiple range test among sampling dates ($p \leq 0.05$)

² Abbreviations: CC, Clearcut; PC, Patch Cut; GT, Green Tree; SW, Shelterwood; OG, Old Growth

³ Multiple range test among treatments ($p \leq 0.05$)

D. Tree water (midday xylem water potential; MPa)

Month	Species ²	Silviculture systems treatments ¹			
		CC	PC	GT	SW
July	Ba	b	a	a	a ³
		A	A	A	A ⁴
	Hw	b	a	ab	ab
		A	A	B	A
September	Ba	a	a	a	a
		A	A	A	A
	Hw	a	a	a	a
		A	A	A	A

¹ Silviculture systems treatments abbreviations:

CC, Clearcut; PC, Patch Cut; GT, Green Tree; SW, Shelterwood; OG, Old Growth

² Species abbreviations: Ba, amabilis fir; Hw, western hemlock

³ Multiple range test among treatments ($p \leq 0.05$)

⁴ Multiple range test between species within months ($p \leq 0.05$)

E. Height growth (cm):

Species ²	Silviculture systems treatments ¹				
	CC	PC	GT	SW	OG
Ba	a	a	a	a	b ³
	A	A	A	A	A ⁴
Hw	a	a	a	a	b
	A	B	A	A	A

¹ Silviculture systems treatments abbreviations:
CC, Clearcut; PC, Patch Cut; GT, Green Tree; SW, Shelterwood; OG, Old Growth

² Species abbreviations: Ba, amabilis fir; Hw, western hemlock

³ Multiple range test among treatments ($p \leq 0.05$)

⁴ Multiple range test between species ($p \leq 0.05$)

F. Specific leaf area (cm²/g):

Species ²	Silviculture systems treatments ¹				
	CC	PC	GT	SW	OG
Ba	b	b	b	b	a ³
	A	A	A	A	A ⁴
Hw	c	bc	bc	b	a
	B	B	B	B	B

¹ Silviculture systems treatments abbreviations:
CC, Clearcut; PC, Patch Cut; GT, Green Tree; SW, Shelterwood; OG, Old Growth

² Species abbreviations: Ba, amabilis fir; Hw, western hemlock

³ Multiple range test among treatments ($p \leq 0.05$)

⁴ Multiple range test between species ($p \leq 0.05$)

Rates of Organic Matter Decomposition and Nitrogen Mineralization in Forest Floors at MASS

Cindy E. Prescott
Faculty of Forestry
University of British Columbia
Vancouver, B.C., V6T 1Z4

Introduction

The interrelated processes of decomposition and mineralization are critical to the recycling of nitrogen, as the nitrogen bound in organic matter is released in forms available for uptake by plants. These processes are carried out by microorganisms in the forest floor, so the rates are affected by factors which influence microbial activity, primarily moisture, temperature and the nature of the organic material. Clearcutting and other silvicultural systems affect each of these factors, and so have the potential to substantially alter rates of decomposition and N mineralization in forest floors.

Leaching of N from soils has often been reported after clearcutting forests, and has been attributed to accelerated decomposition and nutrient mineralization of the residual organic matter. Although it is generally considered that clearcutting forests results in more rapid decomposition than in the uncut forest, rates may actually be faster, slower, or the same in clearcuts (Binkley 1984, Yin *et al.* 1989). Thinning may also increase (Piene and Van Cleve 1978), decrease (Weetman 1965) or have no effect (Will *et al.* 1983) on decomposition rates. Very little is known about the effects of different opening sizes or partial removals on decomposition rates. The effects may increase linearly with increasing basal area removal, or there may be a threshold level at which rates are affected. Most studies of the effects of cutting have investigated decomposition of fresh litter; much less is known about the influence on the rate of decomposition of the residual forest floor material in cut plots. Reductions in forest floor mass have been frequently reported after clearcutting, and attributed to increased decomposition. However, this is not consistently found, and could also result from reduced litter inputs after cutting. Clearcutting may also have different influences on decomposition rates at different depths in the forest floor (Binkley 1984, Yin *et al.* 1989).

Rates of net N mineralization in the forest floor and soil usually increase after cutting, and this is usually attributed to greater microbial activity resulting from the warmer, moister conditions in clearcuts (Edmonds and McColl 1989, Frazer *et al.* 1990, Smethurst and Nambiar 1990). However, it may also be due to reduced litter input, reduced plant uptake of N, and decay of dead roots and slash in clearcuts (Vitousek 1981), rather than changes in microclimate. Little is known about the effect of opening size or partial removals on N mineralization (i.e., whether to expect a gradient or a threshold effect). In lodgepole pine forests, higher rates of net N mineralization have been reported in a 0.25 ha patch cut (Prescott *et al.* 1992), and after removal of at least 15 trees (Parsons *et al.* 1994).

Rates of decomposition and N mineralization in the forest floors were measured in the 5 treatments in the MASS experiment (Clearcut, Patch Cut, Green Tree Retention, Shelterwood and Old Growth), to address the following questions:

1. Are rates of litter decomposition faster in the clearcut?
2. Are rates of decomposition related to the basal area removed in each treatment?
3. Are rates of N mineralization faster in the clearcut?
4. Are rates of N mineralization related to the basal area removed in each treatment?
5. Are differences in rates of N mineralization a result of differences in microclimate or in the nature of the forest floor in each of the treatments?

Study Site and Treatments

The study site is in the Iron River operation of Menzies Bay Division of MacMillan Bloedel Ltd., near Campbell River on Vancouver Island, B.C., in the Montane Moist Maritime Coastal Western Hemlock biogeoclimatic variant (CWHmm2, formerly CWHb4). There are 3 replicates of each of three silvicultural systems: Patch Cut, Shelterwood and Green Tree Retention, and adjacent Clearcut and Old Growth areas. Each replicate occupies a minimum 9-hectare area (250 m × 360 m). The treatment area was divided into nine blocks, and three groups of the three treatments were assigned randomly within each group. The Clearcut treatment was assigned to a large neighboring clearcut, rather than 9 ha clearcuts interspersed within the other treatments in order to be representative of current and past practices. The Old Growth (uncut) treatment was also assigned to a single larger area, rather than three 9 ha blocks, to minimize edge effects. The Clearcut is a 69 ha area cut during 1992 and 1993; all other areas were harvested in 1993. In the Patch Cut treatment, all stems were harvested in three 1.5 ha patches (approximately 120 m × 125 m) within each of the three 9 ha treatment blocks. The remaining areas will be harvested after regeneration reaches 10 m in height. In the Green Tree treatment, 25 stems/ha of lower value dominants and codominants, plus a mixed species composition of healthy intermediates were left standing. In the Shelterwood treatment, 30% of the basal area (about 200 stems/ha over 17.5 cm DBH), representing the entire stand profile were left.

Methods

Organic Matter Decomposition

Rates of mass loss were measured using the litterbag technique, in which known-weight samples of organic matter are enclosed in fibreglass mesh bags and incubated on site. Litterbags were installed in one plot of each treatment on November 15–16, 1993. In each plot, bags were installed at 35 stations in the vicinity of the climate station. At each station, there were 4 litterbags, containing 2.0 g of western hemlock and amabilis fir needle litter, lodgepole pine needle litter, aspen leaf litter, or forest floor (FH layers) material. The mixed hemlock and fir litter was collected from an old-growth forest at the MASS site in 1993; the other materials are standard substrates being used in an extensive comparative decomposition experiment. Bags containing foliar litter were pinned to the surface of the forest floor; bags containing forest floor material were buried in the forest floor. Bags were constructed of fibreglass screening and are about 10 x 10 cm or 15 x 15 cm in size. Bags containing hemlock/fir needles and forest floor material had a double layer of screening to reduce spillage. At yearly intervals for 5 years, all bags will be collected from 7 stations in each plot. The contents of each bag are dried and weighed to determine the rate of decomposition of each litter type in each plot. Only the first-year results (from the November 1994 collection) are presented in this report.

Net Nitrogen Mineralization

Experiment 1: Rates of N mineralization during in situ incubation

In this experiment, rates of net N mineralization in forest floor material from each plot were measured during a 5-week incubation in the same plot. Five samples of the forest floor (FH layers) were collected from each of the 3 plots of each treatment in May 1994. Three temporary plots were established within the existing Clearcut and Old Growth sites. Samples from the Clearcut were taken from the area harvested in 1993 so that they represent the same time since disturbance as the other treatments, but were incubated in the area clearcut in 1992 so that the microclimate information from this area would be relevant. All coarse roots and live vegetation were removed and each sample was mixed well. One 100 g subsample of each sample was put into a polyethylene bag, sealed, and inserted into the forest floor near the place from which it had been removed, except for the Clearcut. After 5 weeks, the bags were retrieved and final concentrations of KCl-extractable NH_4 and NO_3 were measured to estimate mineralizable N in each sample. Differences in mineralizable N among treatments were used to determine the influence of the treatments on rates of N mineralization in the forest floor.

Experiment 2: Rates of N mineralization in transplanted forest floor material

To determine the influence of different microclimatic conditions in the treatments, rates of N mineralization were measured in forest floor material from the old-growth forest during incubation in plots in each treatment. Fifteen samples of forest floor FH material were collected from the Old Growth forest in May 1994. All coarse roots and live vegetation were removed and each sample was mixed well. Fifteen 100 g subsamples of each sample were put into polyethylene bags and sealed. Five bags were inserted into the forest floor in each of the 3 plots of each treatment, alongside the samples from that plot from Experiment 1. After 5 weeks, the bags were retrieved and final concentrations of KCl-extractable N were measured. Differences in mineralizable N among treatments were used to determine the influence of microclimate changes on rates of N mineralization in the forest floor.

Experiment 3: Rates of net N mineralization during laboratory incubation

This experiment was to test the influence of differences in the nature of the residual forest floor in each treatment on rates of N mineralization under standard conditions in the laboratory. Five forest floor samples were collected from the 3 plots of each treatment in August 1994, sorted and mixed. A subsample of each sample was remoistened to 75% water, placed in polyethylene bags and incubated in the lab at about 20°C for six weeks. The original moisture contents of these samples ranged from 18% to 71%. Concentrations of KCl-extractable N in each sample were measured after incubation, to estimate mineralizable N in each sample. This provided an indication of the mineralization potential of each forest floor sample, and of the influence of differences in the nature of the residual forest floor in each treatment.

Experiment 4: Rates of CO_2 evolution during laboratory incubation

A subsample of each of the 5 forest floor samples from each plot from Experiment 1 was remoistened to 75% water, placed in a 470 mL (1 pint) canning jar and incubated in the lab at about 20°C for 5 weeks. Original moisture contents, estimated by oven-drying portions of each sample at 65°C, were all between 60% and 78%. At weekly intervals, a sample of the gas in each jar was extracted with a syringe and concentrations of CO_2 -C in each jar were measured. After extraction, the jars were opened to outside air for 5 minutes. The amount of CO_2 -C produced weekly in each jar was summed for the 6 week incubation to estimate cumulative C mineralization.

This provided an indication of rates of decomposition and microbial activity in each forest floor sample.

For all measurements, mean values for the 5 treatments were compared with one-way ANOVA and Bonferroni's multiple range test, using SPSS for Windows.

Results

Organic Matter Decomposition

After decomposing for one year, the weight of pine needle litter remaining in the bags was significantly less in the Old-growth forest than in the other treatments (Table 1). Hemlock/fir needle litter also decomposed significantly faster in the Old Growth forest than in the Patch Cut or Green Tree treatments; the Shelterwood and Clearcut were intermediate. There were no significant differences in the mass of aspen leaf litter or forest floor material remaining in any of the treatments.

Table 1. Weight remaining (g) of four litter types after decomposing for one year in the five silvicultural treatments

Treatment	Hemlock	Pine	Aspen	Forest Floor
Clearcut	1.46 (0.06) <i>ab</i>	1.39 (0.08) <i>b</i>	1.08 (0.08) <i>a</i>	1.86 (0.04) <i>a</i>
Green Tree	1.55 (0.07) <i>b</i>	1.43 (0.04) <i>b</i>	1.15 (0.11) <i>a</i>	1.85 (0.07) <i>a</i>
Shelterwood	1.45 (0.10) <i>ab</i>	1.45 (0.05) <i>b</i>	1.20 (0.09) <i>a</i>	1.89 (0.05) <i>a</i>
Patch Cut	1.50 (0.06) <i>b</i>	1.41 (0.06) <i>b</i>	1.13 (0.18) <i>a</i>	1.88 (0.05) <i>a</i>
Old Growth	1.32 (0.13) <i>a</i>	1.24 (0.08) <i>a</i>	1.10 (0.05) <i>a</i>	1.85 (0.03) <i>a</i>

Note: Each value is the mean (and standard deviation) of 7 samples per treatment. Mean values for each treatment followed by the same letter are not significantly different ($p < 0.05$) based on one-way ANOVA and Bonferroni's multiple range test.

Nitrogen Mineralization

Experiment 1: Mineralizable N during in situ incubation

Concentrations of extractable N in forest floor samples after the 5-week *in situ* incubation were higher in the Clearcut than in the Old Growth treatment, and the other treatments were intermediate (Table 2). There was not a clear relationship between basal area removed and mineralizable N (i.e., rates did not increase in the order Old Growth < Green Tree < Shelterwood < Clearcut). Most of the N was in the form of $\text{NH}_4\text{-N}$.

Table 2. Mineralized N (mg/g) in forest floor material after a 5-week incubation in the five silvicultural treatments

Treatment	n	$\text{NH}_4\text{-N}$	$\text{NO}_3\text{-N}$	Total N
Clearcut	15	0.371 (0.270) a	0.006 (0.009) a	0.377 (0.270) a
Green Tree	15	0.176 (0.126) ab	0.003 (0.007) a	0.178 (0.126) ab
Shelterwood	15	0.275 (0.269) ab	0.003 (0.006) a	0.278 (0.270) ab
Patch Cut	15	0.263 (0.264) ab	0.002 (0.004) a	0.265 (0.262) ab
Old Growth	15	0.099 (0.084) b	0.005 (0.013) a	0.106 (0.081) b

Note: Each value is the mean (and standard deviation) of 5 samples per plot and 3 plots per treatment. Mean values for each treatment followed by the same letter are not significantly different ($p < 0.05$) based on one-way ANOVA and Bonferroni's multiple range test.

Experiment 2: Mineralizable N in transplanted forest floors

Concentrations of extractable N in Old Growth forest floor material after the 5-week incubation were greatest in the Patch Cut and least in the Clearcut (Table 3). This indicated that differences in microclimate were not responsible for the higher rates of N mineralization in the Clearcut during the *in situ* incubation (Experiment 1). There was very little $\text{NO}_3\text{-N}$ in any of the samples.

Table 3. Mineralized N (mg/g) in forest floor material from the Old Growth forest during a 5-week field incubation in the five silvicultural treatments

Treatment	n	$\text{NH}_4\text{-N}$	$\text{NO}_3\text{-N}$	Total N
Clearcut	14	0.064 (0.045) b	0.000 (0.001) a	0.064 (0.045) b
Green Tree	15	0.106 (0.060) ab	0.003 (0.006) a	0.109 (0.062) ab
Shelterwood	14	0.085 (0.030) ab	0.000 (0.000) a	0.085 (0.030) ab
Patch Cut	12	0.277 (0.397) a	0.004 (0.006) a	0.281 (0.398) a
Old Growth	15	0.099 (0.084) ab	0.005 (0.013) a	0.104 (0.081) ab

Note: Each value is the mean (and standard deviation) of 5 samples per plot and 3 plots per treatment. Mean values for each treatment followed by the same letter are not significantly different ($p < 0.05$) based on one-way ANOVA and Bonferroni's multiple range test.

Experiment 3: Mineralizable N during laboratory incubation

The amount of extractable N at the end of the laboratory incubation was greatest in the Clearcut and least in the Shelterwood (Table 4). This suggests that the nature of the forest floor material was responsible for the higher rates of N mineralization in the Clearcut.

Table 4. Mineralized N (mg/g) in forest floor material from each silvicultural treatment during a 5-week incubation in the laboratory

Treatment	n	NH₄-N	NO₃-N	Total N
Clearcut	14	0.742 (0.551) <i>a</i>	0.004 (0.005) <i>b</i>	0.747 (0.552) <i>a</i>
Green Tree	15	0.581 (0.706) <i>ab</i>	0.014 (0.013) <i>ab</i>	0.545 (0.703) <i>ab</i>
Shelterwood	14	0.192 (0.233) <i>b</i>	0.015 (0.013) <i>ab</i>	0.207 (0.231) <i>b</i>
Patch Cut	12	0.678 (0.392) <i>ab</i>	0.012 (0.013) <i>ab</i>	0.690 (0.395) <i>ab</i>
Old Growth	15	0.413 (0.297) <i>ab</i>	0.025 (0.023) <i>a</i>	0.438 (0.294) <i>ab</i>

Note: Each value is the mean (and standard deviation) of 5 samples per plot and 3 plots per treatment. Mean values for each treatment followed by the same letter are not significantly different ($p < 0.05$) based on one-way ANOVA and Bonferroni's multiple range test.

Experiment 4: Rates of CO₂-C evolution during laboratory incubation

Rates of CO₂-C evolution during the 5-week laboratory incubation were greater in forest floor material from the Green Tree than in Patch Cut or Old Growth forest floors (Table 5). This may have been related to the remoistening of samples to constant moisture contents prior to incubation. Green Tree forest floor samples were the driest and so received the most water, whereas samples from the Patch Cut, Old Growth and Shelterwood treatments received the least water.

Table 5. Rate of respiration (mg CO₂-C/g/d) and moisture content (%) of forest floor material from the five silvicultural treatments during a 5-week incubation in the laboratory

Treatment	n	Respiration	Moisture Content
Clearcut	15	0.22 (0.076) <i>ab</i>	0.72 (0.072) <i>ab</i>
Green Tree	15	0.24 (0.054) <i>b</i>	0.68 (0.10) <i>a</i>
Shelterwood	15	0.21 (0.072) <i>ab</i>	0.74 (0.036) <i>b</i>
Patch Cut	15	0.17 (0.081) <i>a</i>	0.75 (0.038) <i>b</i>
Old Growth	15	0.18 (0.044) <i>a</i>	0.74 (0.028) <i>b</i>

Note: Each value is the mean (and standard deviation) of 5 samples per plot and 3 plots per treatment. Mean values for each treatment followed by the same letter are not significantly different ($p < 0.05$) based on one-way ANOVA and Bonferroni's multiple range test.

Discussion

Rates of litter decomposition during the first year were faster in the Old Growth forest than in the clearcut. This may have resulted from different moisture conditions in these treatments. The foliar litter was pinned on the surface of the forest floor, which was very dry in the clearcut during the summer. Alternatively, the higher rates of decomposition in the Old Growth forest may reflect more intact communities of microorganisms and soil fauna in the undisturbed forests. Litter decomposition was slower in the alternative silvicultural treatments, and did not show a clear relationship to basal area removed.

The greater concentrations of mineralizable N in the Clearcut is in keeping with other reports of increased rates of N mineralization after clearcutting forests (Edmonds and McColl 1989, Frazer *et al.* 1990, Smethurst and Nambiar 1990). This did not appear to be the result of different microclimatic conditions in the Clearcut, since transplanted Old-growth forest floor did not mineralize N faster in the Clearcut. Rather, it appeared to result from differences in the nature of the forest floor material, since material from the Clearcut also mineralized more N during the laboratory incubation, during which microclimatic conditions were the same for all treatments. The faster mineralization of N in the Clearcut does not appear to be related to rates of microbial activity and decomposition, since rates of CO₂ evolution and decomposition were not higher in the Clearcut. It is probably related to reduced input of carbon in fresh litter in the Clearcut, which would reduce the rate at which N is immobilized into microbial biomass, thereby increasing the amount of N which remains in the extractable pool. Hart *et al.* (1994) demonstrated increased net N mineralization once the supply of available C to microorganisms had been exhausted during long-term incubations. A similar situation may exist in forest floors in clearcuts that are deprived of carbon inputs in fresh litter following removal of the trees. Thus, high rates of N mineralization in clearcuts may be related more to the changes in C supply than alterations in microclimate.

The lack of a clear gradient in concentrations of mineralized N between Clearcut, Green Tree, Shelterwood and Old Growth suggests that rates of N mineralization in the forest floor cannot be predicted from basal area removed. Additional studies are needed to elucidate the effects of alternative silvicultural systems on rates of decomposition and N mineralization.

The results of this study are from a single incubation of forest floor material during the early summer of the first year after harvesting. More comprehensive sampling throughout the year is necessary to establish the magnitude of the differences between treatments on an annual basis. Nevertheless, some conclusions pertinent to the original questions can be drawn:

1. Litter decomposition was fastest in the Old Growth forest.
2. There was not a clear relationship between rates of decomposition and basal area removed in each treatment.
3. N mineralization was fastest in the Clearcut and slowest in the Old Growth forest.
4. There was not a clear relationship between rates of N mineralization and basal area removed in each treatment.
5. The faster N mineralization in the Clearcut resulted from differences in the nature of the forest floor material, rather than alterations in the microclimate in the Clearcut.

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Influence of Alternative Timber Harvesting Regimes in Montane Coastal Western Hemlock Zone Forests on Soil Nutrient Leaching: Initial Results

M. C. Feller and P. Olanski
Faculty of Forestry
University of B.C.
Vancouver, B.C. V6T 1Z4

Introduction

Some of Canada's most productive forests occur on Vancouver Island. These forests, like those of most of coastal B.C., have been harvested for timber, almost solely by clearcutting. Regeneration of many of these forests following harvesting has been successful. However, both natural and artificial regeneration of montane forests on Vancouver Island, consisting of western and mountain hemlock, amabilis fir, western redcedar, and yellow cedar, has often been characterized by poor stocking and growth stagnation (Beese¹ 1992, Koppenaar and Mitchell 1992). The ecological processes operating in these forests are poorly understood. The regeneration and growth problems encountered in them are considered to be probably due to environmental conditions on large clearcuts that create unfavourable microclimate, vegetation competition, or soil conditions for subsequent tree growth.

Poor regeneration with associated slow growth has also been reported for western redcedar–western hemlock–amabilis fir forests on northern Vancouver Island (Weetman *et al.* 1989b, 1993). Studies have implicated nutrients as a cause of the problems, as a result of either a lack of available nutrients in the surface soil (e.g., Prescott *et al.* 1993) or competition for nutrients by salal, a shrub which thrives in some post cutting environments (e.g., Weetman *et al.* 1989, 1993). In the drier climates of eastern Vancouver Island, salal does not appear to impose nutritional limitations on Douglas-fir growth (Klinka *et al.* 1989), although it may compete with Douglas-fir for water (Black *et al.* 1980). These results, together with the relative lack of studies of the ecological processes in forests, clearly prevent generalizations being made at the moment, particularly with respect to the impact of partial cutting on these processes.

The montane forests of Vancouver Island have usually developed on young glacially-derived soils which are acidic and have a low base saturation. They also have thick forest floors. Podzolization and low rates of organic matter decomposition are thought to explain these soil conditions. Low nutrient availability is thought to be the net result of these processes. Following clearcutting, decomposition rates and nutrient availability are thought to increase, temporarily increasing nutrient availability. However, enhanced leaching (podzolization), nutrient immobilization in vegetation, and reduced litterfall have been postulated to relatively quickly decrease nutrient availability, causing growth stagnation (Kumi² 1992). The effect of partial cutting systems on these soil nutrient processes, in comparison to clearcutting, is unknown. If partial cutting results in lower nutrient losses and more sustained higher soil nutrient availability, then it may be preferable to clearcutting as a silvicultural system.

¹ W.J. Beese, MASS Working Plan 1992/1993, MacMillan Bloedel Ltd., Nanaimo, B.C.

² Effects of silvicultural systems on organic matter decomposition and nutrient leaching in a montane forest. Appendix 6.

There are many processes contributing to successful regeneration of forests and maintenance of their productivity (Perry *et al.* 1989). Many of these processes are being studied in a large collaborative study (MASS) established in 1992 by MacMillan Bloedel Ltd., the Canadian Forest Service, and other organizations (Beese³ 1992). The present study is part of the larger MASS study and is assessing the impacts of different cutting systems on nutrient movement through the soil.

Numerous studies have shown that timber harvesting has affected ecosystem nutrient status and nutrient leaching through soil (Anon. 1979, Bormann and Likens 1979, Johnson *et al.* 1982, Perry *et al.* 1989), but nearly all of these studies have involved clearcutting. From those studies that have compared the effect on nutrients of both clearcutting and partial cutting, it appears that partial cutting causes less leaching of nutrients into streamwater, although this can depend on the location of cutting in relation to a stream (Martin and Pierce 1980, Tiedemann *et al.* 1988). With regard to soil and soil solution nutrient levels, however, neither Stark (1979) nor McLurkin *et al.* (1987) found consistent relationships between nutrient levels and cutting intensity. Thus, the impacts of partial cutting and soil nutrients is poorly understood at present and, again, generalizations can not be made.

The present study has, as a general objective, the quantification of the impact of each of the different timber harvesting treatments conducted at the MASS study site (Clearcut, Patch cut, Shelterwood, and Green Tree Retention) on nutrient (N, P, K, S, Mg, and Ca) leaching through soil.

Specific objectives of the study are:

- 1) To quantify nutrient leaching through soil in undisturbed and cut forests and under gradients of environmental parameters thought to affect such nutrient leaching.
- 2) To develop equations which can be used to predict nutrient leaching through soil beneath partially cut forest.

The study began in 1992 and, with only one year of post-harvesting data, is not yet complete. This report describes the study and discusses some initial results which have forest management ramifications.

Methods

This study is being conducted as part of the MASS study whose field site is located approximately 20 km SW of Campbell River on Vancouver Island. To minimize site variability in the field, the study is being conducted on one ecosystem type only—the mesic CWHmm2/HwBa Pipecleaner moss site series (Banner *et al.* 1990), which is the dominant ecosystem within the study area. The study site is located at an elevation of 740–850 m in the Montane Moist Maritime Coastal Western Hemlock biogeoclimatic variant. All cutting treatments occurred during 1993, being completed by December.

The MASS study includes replicates of each of four silvicultural systems with adjacent old-growth forest. The silvicultural systems are Clearcutting (69 ha), small Patch (1.5 ha) Cutting, Shelterwood (retaining 30% of the basal area, or approximately 200 stems/ha), and Green Tree Retention (retaining approximately 25 stems/ha). With the exception of the Clearcuts, individual treatment blocks are approximately 9 ha in size. To accurately measure soil nutrient leaching in each of the 4

³ W.J. Beese, MASS Working Plan 1992/1993, MacMillan Bloedel Ltd., Nanaimo, B.C.

cutting treatments and the undisturbed forest would require a prohibitively large number of collectors, given the great environmental variability in each of the treatments, but particularly in the partial cutting treatments. The most feasible solution to this problem was considered to be to measure nutrient leaching at specific locations within the treatment areas under the complete range of the environmental parameters thought to influence leaching, then develop equations relating nutrient leaching to these parameters, which are measured at each leachate collector. Measuring these parameters in each cutting treatment area and applying the equations should allow estimation of nutrient leaching for each treatment. To facilitate studying the complete variation in any parameter, gradients from complete cutover to undisturbed forest, as well as partially cut forest areas, are being used. The gradients are being obtained at forest-cutover edges. Regression equations to predict nutrient leaching through soil have already been successfully developed using mineral soil properties and leachate volumes (Terry and McCants 1970), supporting the feasibility of successfully developing them in the present study.

As incoming solar radiation is considered to be a key parameter, two forest-cutover edge situations are being studied: one with forest to the north and cutover to the south, and another with forest to the south and cutover to the north. At each edge studied, sampling sites are located along transects running at right angles to the edge line. One sampling site is at the edge, another two–10 m away on either side, another two–30 m away on either side, and a third pair–60 m away on either side. The average canopy height is 28 m, with some dominant trees 45 m in height. Three transects have been established at each edge and there are two replicates of each situation. An additional 2 transects, each containing 7 sampling sites, located approximately 20 m apart, were established in a partially cut (Shelterwood) area. As a result, there are a total of $[2 \text{ (edge situation)} \times 3 \text{ (transects)} \times 7 \text{ (sampling sites per transect)} \times 2 \text{ (replicates)}] + [1 \text{ (partial cut)} \times 2 \text{ (transects)} \times 7 \text{ (sampling sites per transect)}] = 98$ sampling sites.

At each sampling site, a forest floor leachate and a mineral soil leachate collector have been established. The forest floor leachate collector is a tensionless lysimeter consisting of a plastic Buchner funnel, (approximately 13 cm diameter) containing a forest floor core, draining into a 4 L polyethylene bottle. The collector is placed in a hole dug into the soil such that the bottom of the forest floor core is level with the bottom of the surrounding forest floor. Mineral soil and forest floor have been replaced around the collector so that there are no discontinuities at the forest floor surface. Forest floor leachate solutions are obtained from these collectors by means of tygon tubes running from the bottom of the bottles to above the forest floor surface.

Approximately 1–2 m distant from the forest floor leachate collector, on a line parallel to the edge line, a Soil Moisture Inc. soil moisture tube is inserted into the mineral soil, such that the suction cup is located at a depth of 30 cm below the forest floor-mineral soil interface, this being considered to be below the effective rooting zone.

All soil moisture tubes were acid washed and thoroughly cleaned prior to field use. In the field, each tube is evacuated to a pressure of 0.5 bar, which is within the range of 0.3–0.6 bar used by other workers, and not greatly different from the tension at which percolating soil solution would be held (cf. DeByle *et al.* 1988, Nagpal 1982, Severson and Grigal 1976, Silkworth and Grigal 1981).

Although different types of collectors are being used for the forest floor and mineral soil leachates, comparison between the two types of leachates is still likely to be valid (e.g., Hendershot and Courchesne 1991, Litaor 1988). Comparison of the results between treatments will be unaffected by the use of different collectors as, for a given type of leachate, the same type of collector is being used for all treatments.

All leachate collectors are emptied once every 4 weeks or whenever possible during dry or snowpack periods. Samples are collected from each collector for subsequent chemical analysis. Installation of all leachate collectors was completed in June 1994, and collection will occur for 3 post-treatment years.

In the laboratory, each sample is being analyzed for pH (using pH meter with glass and reference electrodes), K, Mg, and Ca (by atomic absorption spectrophotometry using a Varian SpectrAA 10 instrument), and NH_4 , NO_3 , SO_4 , and PO_4 (by colorimetric methods on a Technicon TRAACS 800 instrument). In addition, organic N and P are being determined using a persulphate digestion method (D'Elia *et al.* 1977) and analyzing the NO_3 and PO_4 produced on the Technicon instrument.

Chemical concentrations will be multiplied by water quantities to determine nutrient fluxes in soil solutions. Water quantities will be estimated from daily measurements of precipitation, air temperature, solar radiation, and monthly measurements of throughfall. These measurements will be used to estimate weekly evapotranspiration using an energy balance approach described by McNaughton and Black (1973). Soil water flux will be determined by subtracting evapotranspiration from precipitation. Precipitation, air temperature, and solar radiation measurements are being made by other workers at the MASS study site, and will be made available for the present study. Throughfall has been measured using 10 randomly located throughfall collectors in each of the forest stands in which soil solution is sampled.

The above methods will be used to estimate soil nutrient leaching in the areas in which the leachate samplers are located. In order to estimate this leaching in the different cutting treatments, both soil solution chemical concentrations and soil water fluxes will be estimated for each of the cutting treatments. Soil water fluxes will be estimated as described above, assuming that canopy interception (throughfall) is directly proportional to canopy cover. Soil solution chemical concentrations will be estimated by developing equations which predict these concentrations, using as independent variables a variety of parameters which are expected to influence the concentrations and to be affected by different levels of tree removal. These parameters are 1) incoming solar radiation, 2) quantity of fine slash present, 3) forest floor moisture content, 4) basal area of living trees, 5) percent cover of shrubs and herbs, 6) forest floor temperature, and 7) forest floor depth. Measurement of these parameters in each of the cutting treatment areas, and application of the equations should allow estimation of soil solution chemistry.

The seven parameters have been measured as follows:

- 1) **Incoming solar radiation** – at each leachate sampling site, the percentage of above canopy radiation reaching the forest floor surface was measured using a Decagon Devices sunfleck ceptometer. Measurements were made on one day in each of July, and August, 1994, and averaged.
- 2) **Quantity of fine slash (< 1 cm diameter) present** – was visually estimated for an area of 1 m radius around each leachate sampling site, and placed into one of 3 categories—low, moderate, and high. Destructive measurements of fine slash were conducted away from the sampling sites, to quantify visual estimate categories.
- 3) **Forest floor moisture content** – is being estimated by taking samples (volume approximately 200 ml) near each leachate sampling site on each sampling occasion. Samples are being taken of each of two layers—the 0–10 cm and > 10 cm deep layers, so as not to interfere with the source area of the leachate collectors. Samples are being weighed in

the field, using a portable electronic balance, immediately after collection, then again after oven drying. Moisture content is calculated from the differences between the 2 weighings.

- 4) **Basal area of living trees** – was measured by measuring the breast height diameters of all living trees > 2 m high, within a radius of 15 m from each leachate sampling site.
- 5) **Percent cover of shrubs, herbs and small living trees** (< 2 m high), was visually estimated during July and August, for plots of 1 m radius around each leachate sampling site. This will be done for each year of the study if necessary to allow for changes with time following the treatment disturbances.
- 6) **Forest floor temperatures** are being continuously measured at a limited number of sites using Campbell Scientific CR10 data loggers with multiplexers and thermistor and/or thermocouple temperature probes. Probes were inserted at 5 cm and 15 cm below the forest floor surface within 15 cm of forest floor leachate sampling sites, where possible. In addition, temperatures at depths of 5 and 15 cm in the forest floor were measured using a soil thermometer near each leachate sampling site on each sampling occasion (6 such occasions for 1994) and corrected to 12 noon, Pacific Standard Time, using the results of measurements made at the same place at different times throughout the day.
- 7) **Forest floor depth** was measured for the forest floor core sitting in each forest floor leachate sampler.

In order to apply the prediction equations to the different cutting treatments, measurements of the above 7 parameters are also being made in each of the cutting treatment areas at fixed points on a grid system for parameters 1, 2, 3, 6, and 7, and utilizing data collected by MacMillan Bloedel for parameters 4 and 5.

Initial Results

Soil Solution Chemistry

For each forest floor and mineral soil leachate collector, the annual average chemical concentrations were determined. These averages were calculated from 6 samplings of forest floor leachate (May–October) and 5 samplings of mineral soil leachate (June–October). Missing data resulted in 8 mineral soil leachate collectors being eliminated from the dataset. Thus, the 1994 results are for 98 forest floor and 90 mineral soil leachate collectors.

Chemical concentrations in both forest floor and mineral soil leachates varied widely (Table 1). In general, concentrations were lower in mineral soil than in forest floor leachate.

Table 1. *Ranges of mean annual chemical concentrations (mg/L) and pH values in forest floor and mineral soil leachates collected from the MASS study sites in 1994*

	K	Mg	Ca	PO ₄	NO ₃	NH ₄	Org-N	Org-P	SO ₄	pH
Forest floor leachate	1.3 - 16.6	0.2 - 3.0	0.3 - 9.1	0.1 - 12.2	0.0 - 4.8	0.0 - 3.5	0.0 - 0.2	0.0 - 6.7	3.7 - 10.2	3.3 - 5.6
Mineral Soil leachate	0.1 - 14.3	0.1 - 4.7	0.1 - 7.8	0.0 - 1.5	0.0 - 3.8	0.0 - 0.6	0.0 - 0.4	0.2 - 1.1	0.0 - 0.4	3.7 - 6.8

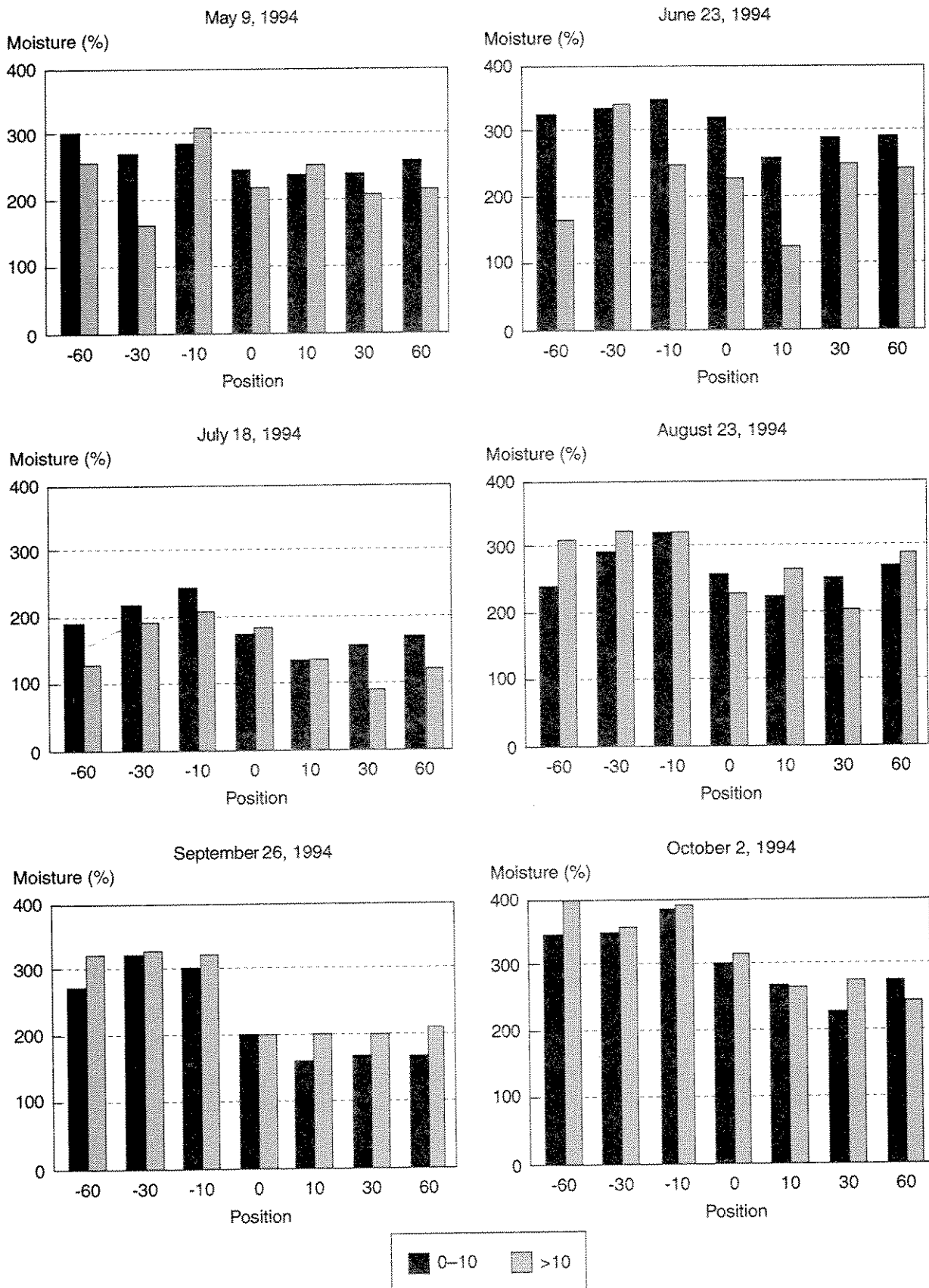


Figure 1. Forest floor moisture content of the 0-10 and >10 cm deep forest floor layers on each sampling date in 1994, averaged over all forest-clearcut transects. Position refers to distance (m) from the forest-clearcut edge, with negative values indicating the clearcut.

Parameters Used To Estimate Soil Leachate Concentrations

- 1) *Incoming solar radiation*: This varied from 0% (in forest) to 100% (in clearcut) of full sunlight.
- 2) *Quantity of fine slash*: Quantification, through destructive sampling, of the visually assessed slash categories, produced 3 distinct classes with individual measurements ranging from 0.0 to 1.7 kg/m². Based on these estimates, it was decided to use 0.2, 0.75, and 1.5 kg/m² as the mass for each of the low, medium, and high categories, respectively.
- 3) *Forest floor moisture content*: Forest floors remained moist for each sampling date, essentially remaining above 100% moisture content (Figure 1). The forest floor in the clearcuts was generally wetter during the growing season, than that in the undisturbed forests.
- 4) *Basal area of living trees*: This was comprised mainly of western hemlock, and had values ranging from 0.0 to 14.6 m² in the vicinity of sampling sites.
- 5) *Percent cover of lower vegetation*: This was comprised mainly of younger tree seedlings then shrubs, with relatively few herbs. The total percent cover varied from 0 to 87%.
- 6) *Forest floor temperatures*: The forest floor temperatures averaged from each of the 5 sampling dates (June through October) ranged from 5.5 to 16.7° C at a depth of 5 cm, and from 3.8 to 13.2° C at a depth of 15 cm.
- 7) *Forest floor depth*: This varied from 4 to 57 cm with 62% of the values > 10 cm and 30% of the values > 20 cm.

Relationships Between Soil Solution Chemistry and Parameters Used to Estimate this Chemistry

Soil solution quantities have not yet been calculated since water flux data are not yet available. In addition, some of the data collected during 1994 require checking during 1995. As a result, attempts have not yet been made to develop regression equations. Preliminary analysis of the data, however, suggests that annual average concentrations of all chemicals measured in forest floor leachate, and all except NH₄ and organic N in mineral soil leachate, can be significantly correlated with one or more of the environmental parameters measured (Table 2). All forest floor leachate nutrient concentrations, except those of organic - P, were significantly correlated with at least one type of tree basal area (Table 2), suggesting that standing trees, particularly cedars, significantly influence forest floor leachate chemistry. Mineral soil leachate chemistry, however, appears to have been more influenced by forest floor properties than by vegetation properties, particularly by forest floor temperature and moisture content. The high correlations between mineral soil leachate Mg and Ca concentrations and forest floor temperatures at a depth of 15 cm, are noteworthy (Table 2).

There are many significant correlations among the chemical concentrations themselves (Tables 3 and 4), including between NH₄ and organic N on the one hand, and other chemical concentrations, on the other, in mineral soil leachate (Table 4). These results, together with the fact that all the environmental parameters studied are potentially affected by harvesting, suggest that the desired regression equations can be successfully developed.

Table 2. Significant correlations between environmental parameters and average leachate concentrations for 1994 from the MASS study site

Chemical	Significantly correlated environmental parameter (Pearson correlation coefficient in parentheses)
a) Forest floor leachate	
K	cedar ba (0.17*)
Mg	ff depth (0.27***), cedar ba (0.19*), tree ba (0.18*)
Ca	cedar ba (0.33***), tree ba (0.25**), ff depth (0.22**), mois (0.19*)
PO ₄	cedar ba (0.28***), tree ba (0.26***), hemlock ba (0.20**), mois (-0.20**)
NO ₃	shrub cov (0.33**), rad (0.24**)
NH ₄	ff depth (-0.33***), fir ba (0.24**)
Org-N	cedar ba (0.28***)
Org-P	rad (0.18*)
SO ₄	rad (-0.28***), fir ba (0.22**)
pH	rad (0.27***)
b) Mineral soil leachate	
K	concov (0.24**), mois (0.18*)
Mg	temp15 (0.70***), ff depth (0.27***), mois (0.19*), temp5 (0.18*)
Ca	temp15 (0.62***), ff depth (0.32***), mois (0.23**), temp5 (0.17*)
PO ₄	mois (0.21**)
NO ₃	temp5 (0.21**), mois (0.19*)
NH ₄	—
Org-N	—
Org-P	temp15 (0.35***), mois (0.31***)
SO ₄	ff depth (0.25**)
pH	mois (0.28***), temp15 (0.23**), temp5 (0.18*)

*** Significant at $P < 0.01$, ** Significant at $P < 0.05$, * Significant at $P < 0.10$.

Environmental parameters are cedar ba = basal area of living western red and yellow cedar trees, concov = percent cover of conifer trees < 2m high, ff depth = forest floor depth, fir ba = basal area of living amabilis fir trees, hemlock ba = basal area of living western and mountain hemlock trees, mois = average sampling period forest floor moisture content of the 0–10 cm layer, rad = percentage of above canopy photosynthetically active radiation, shrub cov = percent cover of shrubs, temp 5 = average sampling period forest floor temperature at a depth of 5 cm, temp15 = average sampling period forest floor temperature at a depth of 15 cm.

Table 3. Correlation matrix for the average chemical concentrations in forest floor leachates for 1994. Pearson correlation coefficients, and their significance, are given

	K	Mg	Ca	PO ₄	NO ₃	NH ₄	Org-N	Org-P ¹	SO ₄
Mg	0.12	1.00							
Ca	0.20*	0.76**	1.00						
PO ₄	0.67**	0.24*	0.18	1.00					
NO ₃	0.01	0.38**	0.28**	-0.10	1.00				
NH ₄	0.36**	0.04	0.03	0.38**	0.03	1.00			
org-N	-0.07	0.39**	0.30**	-0.10	0.64**	0.08	1.00		
org-P	0.17	0.09	0.12	0.36**	0.06	0.11	0.08	1.00	
SO ₄	0.41**	0.15	0.10	0.44**	-0.29**	0.26*	-0.29**	0.05	1.00
pH	-0.11	0.37**	0.36**	-0.26*	0.41**	0.15	0.34**	-0.05	-0.52**

1) Org-N = organic N, Org - P = organic P.

2) * Significant at P < 0.05, ** Significant at P < 0.01. Other values are not significant.

Table 4. Correlation matrix for the average chemical concentrations in mineral soil leachates for 1994. Pearson correlation coefficients, and their significance, are given

	K	Mg	Ca	PO ₄	NO ₃	NH ₄	Org-N	Org-P	SO ₄
Mg	0.41**	1.00							
Ca	0.41**	0.94**	1.00						
PO ₄	0.53**	0.18	0.19	1.00					
NO ₃	0.40**	0.29**	0.35**	0.48**	1.00				
NH ₄	0.54**	0.14	0.12	0.81**	0.17	1.00			
org-N	0.19	0.10	0.06	0.22*	0.36**	0.26*	1.00		
org-P	0.28**	0.41**	0.33**	0.24*	0.22*	0.24*	0.40**	1.00	
SO ₄	0.64**	0.32**	0.38**	0.35**	0.16	0.39**	-0.09	-0.01	1.00
pH	-0.21*	0.20	0.22*	-0.06	0.07	-0.16	0.21*	0.49**	-0.33**

Chemicals and statistical significance are described in Table 3.

Management Implications of These Initial Results

The initial results have the following two major implications for forest management:

1) *Forest floor moisture levels and forest fire danger rating*

Forest floor moisture contents tended to be higher in clearcut than in forested areas, with the differences being particularly noticeable after a drying period in late summer (26 September data in Figure 1). The severity of a forest fire or slashburn includes the magnitude of the impact of the fire on the forest floor, which depends on forest floor moisture content. In the Fire Weather Index System, which is used to predict fire danger, fire behaviour, and fire severity in Canada (e.g., Stocks *et al.* 1989), forest floor moisture content is predicted using models developed for forests alone. Such models are likely to underestimate the moisture content of forest floors in clearcuts, necessitating ecosystem-specific calibration of slashburn severity predictions. Furthermore, fire danger and behaviour in clearcuts will be different from that in forests. A clearcut with little slash may well present a lower fire danger than a nearby forest.

2) *Forest harvesting and nutrient loss*

Forest harvesting will affect the environmental parameters found to be significantly correlated with soil leachate nutrient concentrations. Reduction in tree basal areas may lead to decreases in forest floor leachate concentrations although this is unlikely to be a generalization as a) increases in forest floor moisture may suggest higher Ca concentrations, b) increases in radiation may suggest higher NO₃ and organic P concentrations, c) enhanced shrub growth may also suggest higher NO₃ concentrations, and d) NO₃ concentrations often do not increase for a year or so after forest harvesting (Feller and Kimmins 1984) so the 1995 correlations for NO₃ concentrations may be different from the 1994 correlations.

Positive correlations between mineral soil leachate nutrient concentrations and forest floor moisture and temperature, suggest that most of these concentrations will increase after harvesting, but to a lesser extent after partial cutting than after clearcutting.

As the quantity of water flowing through the soil will increase after harvesting, depending on the relative amount of trees removed, it seems likely that the quantity of nutrients moving through the soil below the rooting zone (i.e., the quantity that is no longer available for vegetation) will also increase, to an extent determined by the degree of tree removal.

The final nutrient prediction equations will not be available for some time. Refinements will be made to the measurements of some of the environmental parameters assessed, and an additional 2 years of data must be collected. However, it does appear that nutrient loss in soil solution in montane CWH forests can be reduced by partial cutting instead of clearcutting.

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Putting MASS in Context: Bird Communities in Vancouver Island Old-Growth Forests

Andrew A. Bryant
Andrew A. Bryant Services
108 Fifth Street
Nanaimo, B.C. V9R 1N2

Introduction

The Montane Alternative Silvicultural Systems (MASS) project is an operational experiment designed to explore the costs, feasibility and ecological ramifications of alternative harvesting methods in high elevation old-growth forests (W. Beese; unpublished MASS Working Plan, June 29, 1992). A site near Campbell River was harvested in 1993 using a combination of clearcutting, clearcutting with reserves (Green Tree Retention), Shelterwood, and small clearcuts (Patch Cut). Logged blocks and an adjacent old-growth control area will be monitored in future years using a variety of methods.

As part of MASS, systematic bird studies were initiated in 1992 to characterize pre-harvest bird communities, nesting status and nest predation rates (Bryant 1994). In this paper I review bird community data in relation to other old-growth stands on Vancouver Island (Bryant *et al.* 1993). My objective is to describe similarities and differences between the MASS site and other old-growth stands, and discuss their implications for future research at MASS and other areas.

Methods

Study Areas

The MASS study area is located between 740 and 850 metres above sea-level within the Georgia Depression Ecoprovince of Vancouver Island (Klinka *et al.* 1991). The stand is dominated by western hemlock (*Tsuga heterophylla*) and amabilis fir (*Abies amabilis*) with varying amounts of western redcedar (*Thuja plicata*), yellow-cedar (*Chamaecyparis nootkatensis*), mountain hemlock (*Tsuga mertensiana*), and Douglas-fir (*Pseudotsuga menziesii*). The area comprises approximately 183 hectares, of which 151 hectares were harvested during the summer of 1993.

Other study areas were located between 20 and 1190 metres above sea-level (Figure 1). At elevations below 500 metres, mature forests on Vancouver Island are typically dominated by western hemlock, western redcedar, amabilis fir, grand fir (*Abies grandis*) and Douglas-fir, while pacific yew (*Taxus brevifolia*) and sitka spruce (*Picea sitchensis*) occur in varying amounts. At higher elevations, mountain hemlock begins to replace western hemlock and yellow-cedar and amabilis fir become more important. Mountainous terrain and differences in slope, aspect, soil and drainage produce substantial differences in vegetation communities.

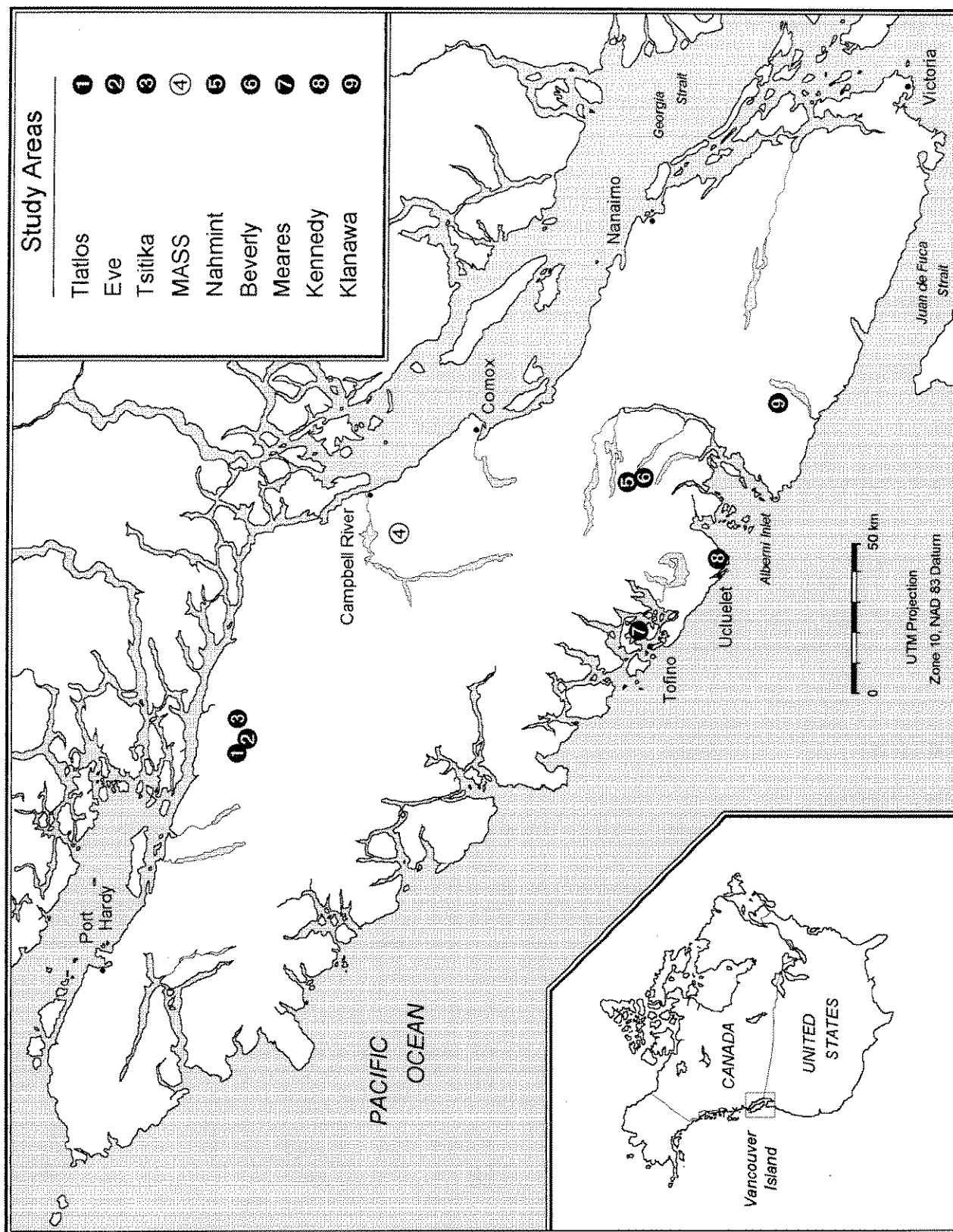


Figure 1. Location of old-growth study areas, including the MASS site near Campbell River.

Bird Counts

Line transects were established in each area with at least 10 sampling stations located >150 metres apart. Where stand size was sufficient, >10 sampling points were established. The MASS transect had 60 stations, Klanawa had 24, Nahmint, Beverly and Meares Island had 12, and Kennedy had 11 sampling stations. However, to facilitate between-area comparisons, 10 sampling stations were randomly selected from each area. Stations were placed away from creeks and riparian vegetation. The Meares transect was situated along an established hiking trail, and the Nahmint, Beverly, Kennedy and Klanawa transects were situated along newly constructed logging roads built during the winter prior to spring logging activities.

Birds were surveyed using fixed-radius point-counts (Hutto *et al.* 1986, Verner 1985). All areas except MASS were surveyed 4 times between 9 May and 7 July 1991. The MASS area was surveyed 4 times between 1 May and 22 June 1992. Counts were made between 0430 hours and 0900 hours, and were not conducted during periods of heavy rain or high winds. Observers recorded all birds seen or heard within 75 metres of a sampling station during a 12 minute period.

Statistical Analyses

Seabirds, shorebirds, hawks and owls were excluded from analysis (Bryant *et al.* 1993). Birds foraging over the plot (e.g., Vaux's Swift), or which entered the plot during the count period (e.g., Red Crossbill) were included. Adequacy of bird sampling efforts was assessed by generating species-accumulation curves for each area, and comparing these with a curve fitted to the data using simple linear regression and log-transformed x values (multiple y values for each x ; Sokal and Rohlf 1981). For other analyses, 10 stations were randomly selected from larger sets in order to standardize sampling effort among areas.

Relative abundance of each species was expressed as the mean (\bar{x}) + standard error (SE) number of individuals detected per sampling station during the 4 surveys. Data for "residents" (those which normally overwinter on Vancouver Island, including altitudinal migrants such as the Dark-eyed Junco), "migrants" (species which normally winter south of Vancouver Island) and cavity-nesters (woodpeckers, creepers, nuthatches and titmice) were analyzed separately. The variability in distribution of species was assessed by calculating coefficients of variation (CV) from \bar{x} abundance per station data across the 9 sites. A lower CV indicates species with similar abundance at all sites. Finally, Pearson correlation analysis was used to test whether individual species were associated with measured habitat variables.

Results

Sampling Effort and Estimates of Community Composition

Species-accumulation curves differed among areas, but most species (57 to 94%) were detected within the first 4 sampling stations (Figure 2). In all cases, addition of samples beyond $n=6$ stations contributed fewer than a proportional number of new species. However, species-accumulation curves never achieved a true asymptote, even for the MASS site, where sampling effort was high ($n=60$ stations). These results suggest that while a few rare species could have been missed, the probability that many species remained undetected was low. Increasing sample sizes beyond 10 stations per area would apparently have had only a small effect on estimates of community composition. Conversely, samples of fewer than 10 stations would probably result in underestimation of species complement, although this would be less of a problem for the MASS site than for richer communities such as the Nahmint or Kennedy sites.

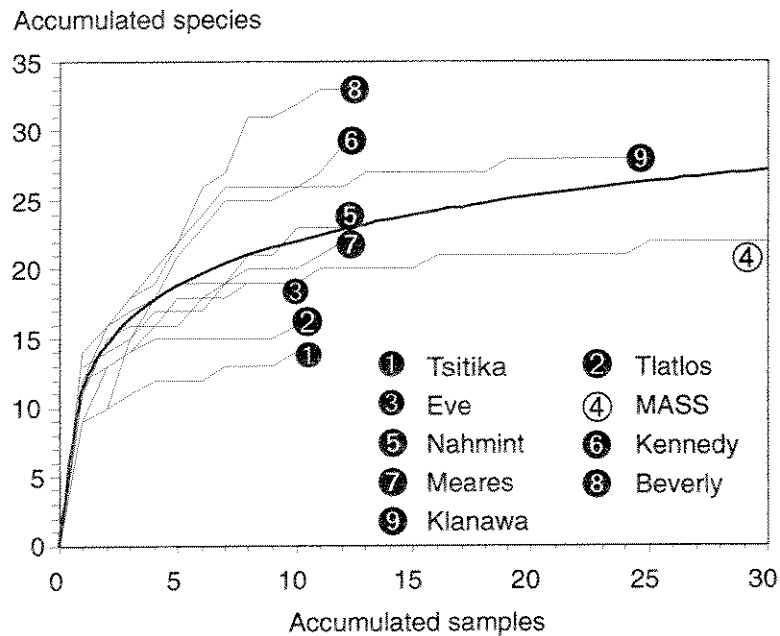


Figure 2. Bird species-accumulation curves for 9 old-growth study sites. The cumulative (bold) curve was generated by linear regression (multiple y values for each x) of species against log-transformed numbers of sampling stations where slope $b = 10.73$ and constant $a = 11.25$. For most sites (including MASS), the majority of species were detected within the first 6 sampling stations. Only 10 stations from each area were used in analyses. For clarity, only 30 stations from the MASS area are shown.

Dominance and Rarity in Old-Growth Forest Bird Communities

A total of 41 species were detected at all sites during surveys, excluding seabirds, shorebirds, raptors and birds judged to be not associated with the sampled habitats. Overall, 10 species (Winter Wren, Chestnut-backed Chickadee, Varied Thrush, Pacific Slope Flycatcher, Golden-crowned Kinglet, Red Crossbill, American Robin, Red-breasted Nuthatch, Brown Creeper and Swainson's Thrush) accounted for 78% of all detections (Table 1). Abundant species typically showed low coefficients of variation, indicating that they were present in most of the sampled stands. Four species averaged over 0.70 detections/station with a CV under 50%: (Winter Wren, Chestnut-backed Chickadee, Varied Thrush and Pacific Slope Flycatcher). Seven other species averaged over 0.10 detections/station with a CV below 100% (Golden-crowned Kinglet, Red Crossbill, American Robin, Red-breasted Nuthatch, Brown Creeper, Swainson's Thrush and Hairy Woodpecker). These species were present in nearly every stand and apparently form the bulk of Vancouver Island old-growth bird communities.

The MASS study area was similarly dominated by a few species. Seven species (Varied Thrush, Chestnut-backed Chickadee, Winter Wren, Red-breasted Sapsucker, Red-breasted Nuthatch, Red Crossbill and Golden-crowned Kinglet) were abundant (>0.5 individuals/sampling station) and accounted for 75% of all bird detections. Another 6 species (Pacific Slope Flycatcher, Dark-eyed Junco, Gray Jay, Brown Creeper, Pine Siskin, and Hermit Thrush) were common (0.1-0.5 individuals/station). Overall, 13 abundant and common species accounted for 97% of all bird detections at the MASS site. The remaining 6 species accounted for fewer than 3% of detections.

Table 1. Relative importance of bird species in old-growth forests of Vancouver Island, and at the MASS site ($n=10$ stations per site). Species are shown in descending rank order of importance. Cumulative data are average numbers/sampling station and coefficients of variation (CV) calculated across 9 study areas. MASS data are average numbers per sampling station. Twenty species which together accounted for <4% of detections in old-growth forests are omitted from this table; all species detected at MASS are included.

All old-growth sites					MASS area	
Species	Average	SD	CV (%)	Cumulative %	Species	Cumulative %
Winter Wren	1.13	0.37	32.98	14.73	Varied Thrush	1.28
Chestnut-backed Chickadee	0.94	0.35	37.66	26.99	Chestnut-backed Chickadee	1.20
Varied Thrush	0.80	0.31	38.72	37.41	Winter Wren	0.88
Pacific Slope Flycatcher	0.77	0.27	35.23	47.40	Red-breasted Sapsucker	0.68
Golden-crowned Kinglet	0.55	0.22	40.02	54.56	Red-breasted Nuthatch	0.65
Red Crossbill	0.51	0.36	70.00	61.25	Red Crossbill	0.63
American Robin	0.42	0.40	97.07	66.68	Golden-crowned Kinglet	0.55
Red-breasted Nuthatch	0.30	0.25	83.84	70.62	Pacific Slope Flycatcher	0.38
Brown Creeper	0.30	0.15	50.19	74.49	Dark-eyed Junco	0.38
Swainson's Thrush	0.23	0.20	86.20	77.50	Gray Jay	0.38
Dark-eyed Junco	0.21	0.26	124.85	80.21	Brown Creeper	0.30
Hairy Woodpecker	0.20	0.14	67.60	82.81	Pine Siskin	0.28
Hammond's Flycatcher	0.20	0.28	140.73	85.42	Hermit Thrush	0.10
Red-breasted Sapsucker	0.15	0.22	148.37	87.37	Steller's Jay	0.05
Hutton's Vireo	0.15	0.20	138.33	89.29	Hairy Woodpecker	0.05
Steller's Jay	0.13	0.17	132.14	90.96	Hammond's Flycatcher	0.03
Townsend's Warbler	0.08	0.11	139.59	91.97	Pileated Woodpecker	0.03
Orange-crowned Warbler	0.08	0.17	231.54	92.95	American Robin	0.03
Rufous Hummingbird	0.07	0.13	181.07	93.89	Common Raven	0.03
Hermit Thrush	0.06	0.07	103.73	94.72		
Gray Jay	0.06	0.12	194.78	95.55		

Trends in Bird Abundance, Richness and Evenness

Bird richness and abundance generally declined from south to north, but evenness was virtually identical at all sites (Figure 3). The MASS site was quite similar to other northern transects (Tsitika, Tlatlos and Eve), containing relatively few species and individuals.

Bird abundance and species richness were negatively correlated with latitude, a relationship attributable to low richness at the Tsitika, Tlatlos, Eve River and MASS stands (Figure 4). In terms of migratory status, residents were not significantly correlated with any habitat variable. However, migrant abundance was negatively correlated with latitude ($r = -0.748$). This reflects the absence of some otherwise common migratory species at northern transects (e.g., Rufous Hummingbird, American Robin, Townsend's Warbler). Woodpeckers were not correlated with any habitat variable, but secondary cavity nesters (Chickadees, creepers and nuthatches) were positively correlated with latitude and elevation ($r = 0.742$ and $r = 0.807$ respectively).

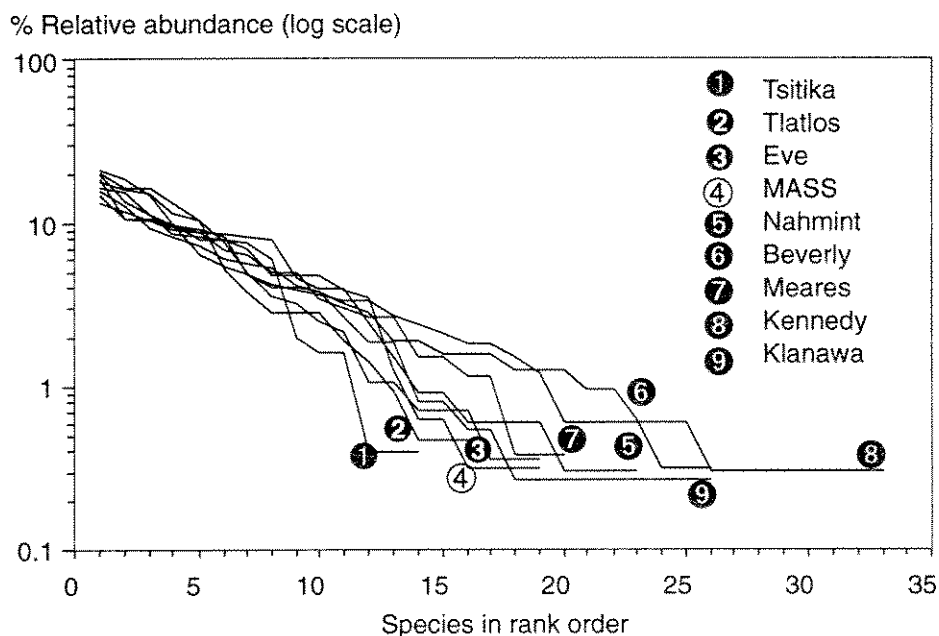


Figure 3. Species evenness at 9 old-growth areas. Data are \bar{x} numbers of each species detected during 4 repeated surveys (plotted in descending rank order on a logarithmic scale). Evenness was remarkably similar for all sampled areas, at least for the most abundant species. The MASS site was similar to other northern transects (Tsitika and Tlatlos), showing low species richness and high dominance by a few species.

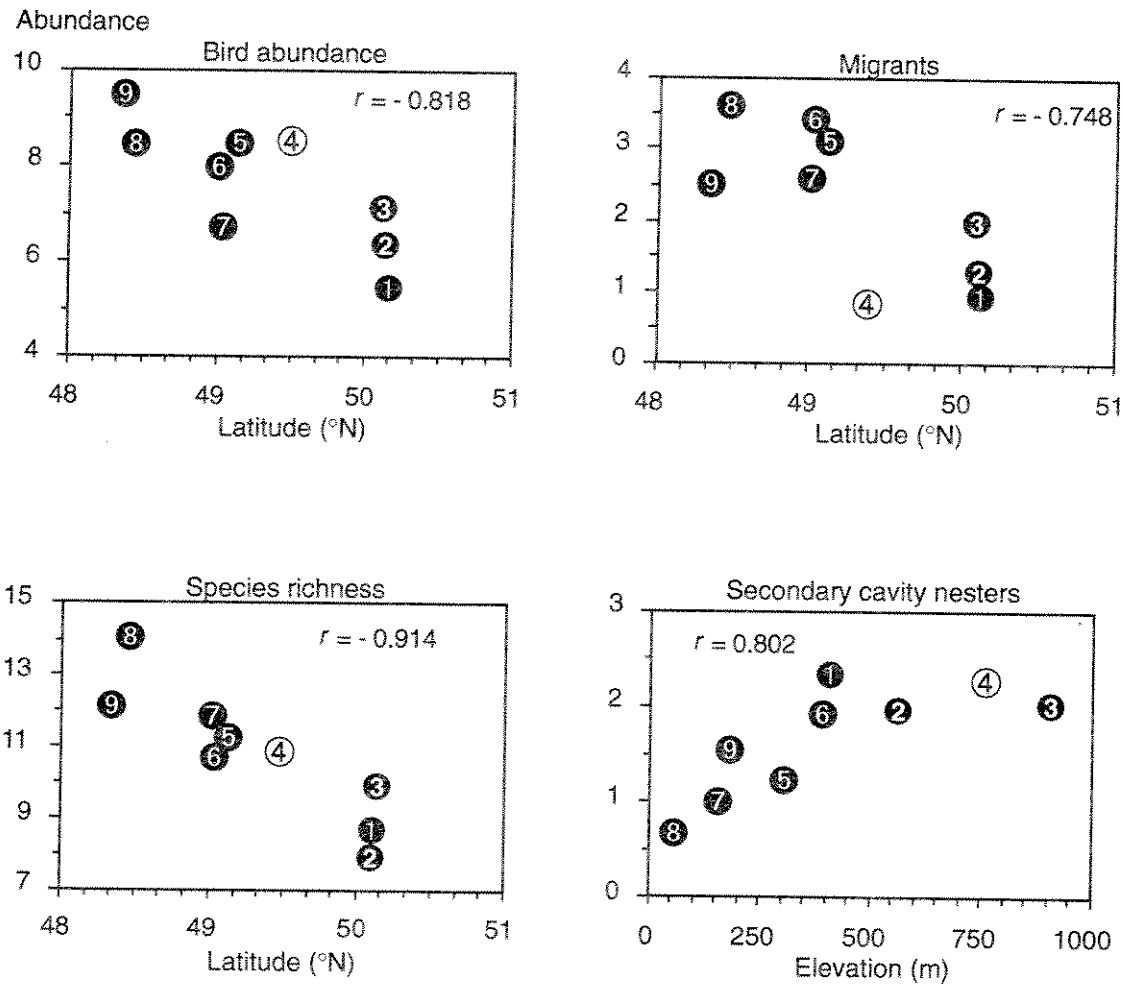


Figure 4. Correlation of habitat variables with elements of bird community structure. Data are \bar{x} values for both bird and habitat data. R values are Pearson correlation coefficients. Site codes are as in Figure 1. The MASS site is characterized by low abundance of migrants, but high abundance of secondary cavity nesters.

Trends in the Distribution of Individual Species

Several species showed large differences in relative abundance among areas (Table 2). Some common species in southern areas were rarely or never detected at the MASS site or other northern areas (Blue Grouse, Rufous Hummingbird, Hutton's Vireo, Orange-crowned Warbler, Townsend's Warbler). Others (Red-breasted Nuthatches, Brown Creepers) were more common in the north. At the high-elevation MASS site, Steller's Jays were partially replaced by Gray Jays, Red-breasted Sapsuckers were extremely common, and migratory warblers were completely absent. The coastal forest at Kennedy Lake had the highest species richness, a result largely due to the presence of several species that prefer open habitats (Barn Swallow, Cedar Waxwing, European Starling and Song Sparrow). Other species achieved their greatest abundance there (Rufous Hummingbird, Northern Flicker, Steller's Jay, American Robin, Orange-crowned Warbler, and Dark-eyed Junco). The Klanawa and Beverly areas also contained relatively high numbers of rare species, with evenness being highest at the latter.

Table 2. Relative abundance of individual species at MASS and other Vancouver Island old-growth forests. Data are \bar{x} (SE) values based on $n=10$ fixed-radius (75 m) sampling plots and 4 repeated counts

Species	Study Site									
	Tsitika	Tlatlos	Eve	MASS	Nahmint	Beverly	Meares	Kennedy	Klanawa	
	\bar{x} (SE)	\bar{x} (SE)	\bar{x} (SE)	\bar{x} (SE)	\bar{x} (SE)	\bar{x} (SE)	\bar{x} (SE)	\bar{x} (SE)	\bar{x} (SE)	
1 Blue Grouse	...	...	...	...	0.08 (0.04)	0.08 (0.04)	...	0.03 (0.03)	0.03 (0.03)
2 Vaux's Swift	...	...	...	...	0.05 (0.05)	0.23 (0.23)	...	...	...
3 Rufous Hummingbird	...	...	...	...	...	0.13 (0.06)	0.18 (0.05)	0.40 (0.06)	0.08 (0.05)
4 Northern Flicker	...	...	0.08 (0.04)	...	...	...	...	0.13 (0.09)	...
5 Red-breasted Sapsucker	...	...	0.05 (0.03)	0.68 (0.15)	0.20 (0.10)	0.30 (0.12)	0.08 (0.04)	...	0.03 (0.03)
6 Hairy Woodpecker	0.10 (0.07)	0.15 (0.04)	0.35 (0.07)	0.05 (0.03)	0.13 (0.04)	0.10 (0.06)	0.10 (0.04)	0.15 (0.04)	0.38 (0.09)	
7 Pileated Woodpecker	...	...	...	0.03 (0.03)	0.03 (0.03)	0.10 (0.07)	...	...	...
8 Olive-sided Flycatcher	...	...	...	...	0.05 (0.05)	0.08 (0.05)	...	0.05 (0.03)	...
9 Western Wood Peewee	...	...	...	...	...	...	...	0.03 (0.03)	...
10 Hammond's Flycatcher	0.03 (0.03)	0.05 (0.03)	0.18 (0.10)	0.03 (0.03)	0.65 (0.14)	0.73 (0.19)	0.03 (0.03)	0.03 (0.03)	0.03 (0.03)	
11 Pacific Slope Flycatcher	0.93 (0.09)	0.70 (0.12)	1.13 (0.16)	0.38 (0.09)	0.73 (0.11)	1.00 (0.12)	0.70 (0.16)	0.33 (0.08)	0.90 (0.15)	
12 Barn Swallow	...	...	...	...	...	...	...	0.05 (0.05)	...
13 Gray Jay	0.10 (0.08)	0.10 (0.06)	...	0.38 (0.13)	...	...	...	...	...
14 Steller's Jay	...	...	0.03 (0.03)	0.05 (0.05)	...	0.13 (0.10)	0.03 (0.03)	0.28 (0.08)	0.18 (0.05)
15 Northwestern Crow	...	...	...	...	...	...	0.20 (0.09)	...	...
16 Common Raven	...	...	...	0.03 (0.03)	...	...	...	0.15 (0.08)	0.03 (0.03)
17 Chestnut-backed Chickadee	1.15 (0.15)	1.08 (0.13)	1.25 (0.19)	1.20 (0.12)	0.70 (0.22)	1.25 (0.19)	0.58 (0.12)	0.28 (0.07)	1.05 (0.24)	
18 Brown Creeper	0.38 (0.15)	0.28 (0.09)	0.53 (0.16)	0.30 (0.07)	0.08 (0.04)	0.10 (0.04)	0.23 (0.09)	0.23 (0.09)	0.35 (0.09)	
19 Red-breasted Nuthatch	0.63 (0.13)	0.55 (0.15)	0.23 (0.12)	0.65 (0.15)	0.33 (0.17)	0.25 (0.12)	0.10 (0.07)	...	0.03 (0.03)	
20 Winter Wren	1.33 (0.27)	0.88 (0.11)	1.05 (0.17)	0.88 (0.08)	1.23 (0.12)	0.65 (0.13)	1.23 (0.14)	0.85 (0.10)	1.83 (0.18)	
21 Golden-crowned Kinglet	0.48 (0.16)	0.20 (0.09)	0.73 (0.15)	0.55 (0.11)	0.85 (0.21)	0.43 (0.11)	0.45 (0.15)	0.30 (0.11)	0.78 (0.15)	

continued next page

Forest stand measurements were poor predictors of abundance for most species (Figure 5). Three species (Chestnut-backed Chickadee, Hermit Thrush, and American Robin) were significantly correlated with elevation ($r = 0.745$, 0.777 and -0.846 respectively). Latitude was negatively correlated with American Robin ($r = -0.909$) and positively correlated with Red-breasted Nuthatch ($r = 0.744$). Hammond's Flycatcher was correlated with distance-to-the-coast ($r = 0.802$). Snag basal area was correlated with Rufous Hummingbird, Steller's Jay and Wilson's Warbler abundance ($r = 0.770$, 0.769 and 0.808 respectively), but this was largely caused by the Kennedy Lake cedar forest. Amabilis fir basal area was correlated with Hermit Thrush ($r = 0.810$). In general, these results suggest that Vancouver Island old-growth forest bird communities are complex and not easily predicted on the basis of easily obtained forest stand data.

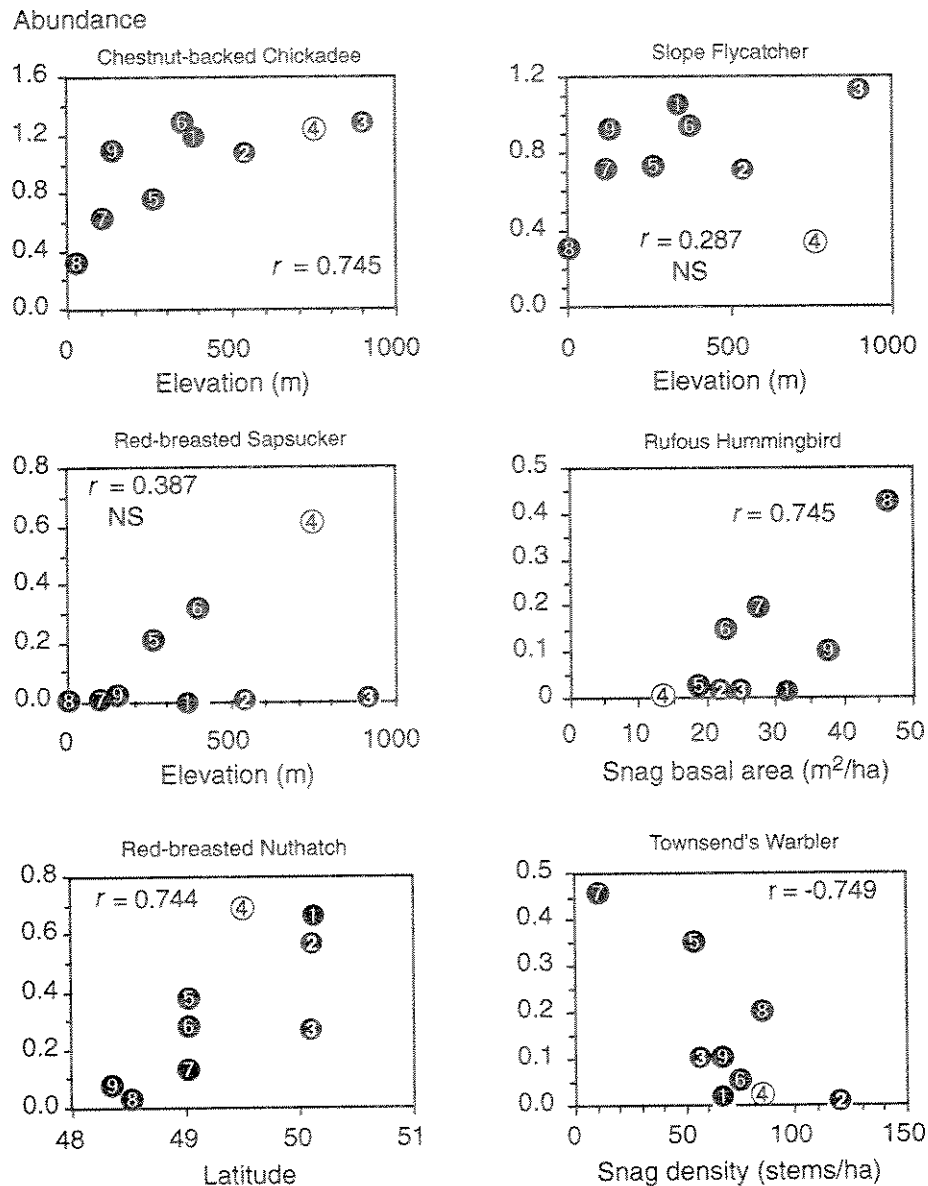


Figure 5. Area-specific abundance of selected species. Data are \bar{x} values per sampling station. Pearson R coefficients are shown. Site codes are as Figure 1. Some resident cavity nesters achieved their highest abundance at the MASS site. Conversely, some migratory species were absent.

Discussion

In some respects the MASS avifauna is typical of Vancouver Island old-growth forests. Communities are composed of a few abundant species and a larger number of rare species that occur consistently, but in much lower numbers. High overall similarity of the nine sampled areas was principally caused by dominance by a few species (especially Winter Wren, Chestnut-backed Chickadee, Varied Thrush, Pacific Slope Flycatcher, Golden-crowned Kinglet, Red Crossbill, American Robin, Red-breasted Nuthatch, Brown Creeper and Swainson's Thrush). Despite this, Vancouver Island old-growth forest bird communities are far from uniform.

The MASS site differed from other sites in its high density of Red-breasted Sapsuckers, and in relatively high numbers of secondary cavity-nesters. The site was also notable for the complete absence of migratory warblers, Rufous Hummingbird, Hutton's Vireo, Swainson's Thrush, and for low numbers of Pacific Slope Flycatchers and American Robins. In essence, the MASS bird community was primarily comprised of resident species in general, and primary and secondary cavity nesting birds in particular. Compared to other sites, rare species (<0.1 birds/station) contributed little to the avifauna, and evenness was relatively high.

Given a 75 metre plot radius, each bird sampling station represented 1.76 hectares of bird habitat. Sampling analysis suggested that most common species will be detected within the first 4 stations, but some species could be missed even in transects with 12 or more stations. This result is congruent with other findings (see Manuwal and Carey 1991), and has important implications. Each alternative silvicultural treatment of Shelterwood, Green Tree Retention and Patch Cut has three replicate blocks 9 ha in size. Because bird plots are circular and treatment blocks are rectangular (250 m × 360 m), each block could realistically contain only 3 stations. Pooling data from the 3 blocks harvested with the same technique would lead to a maximum of 9 bird sampling stations for each treatment type. For rarer species, 9 hectare treatment blocks will be insufficient to detect significant changes caused by harvesting.

The geometry of logging patterns will also have repercussions for future work. The 3 treatment blocks each contain a larger proportion of "edge" habitat than would a single contiguous area with the same number of sampling stations. This preponderance of edge habitat may also cause difficulties in interpreting harvesting effects (e.g., Kroodsma 1984, Forman *et al.* 1976). Nest predation rates may increase as a result of increased abundance of edge species such as Gray and Steller's Jays (Bryant 1994, Wilcove 1985). This needs to be tested; the artificial nest experiment originally conducted in 1992 should be repeated.

Finally, the MASS bird community is unusual in its high proportion of non-migratory residents. For this reason, winter conditions may prove to be even more important than summer ones in structuring bird communities. For small bird species at north temperate latitudes, stored fat reserves are often sufficient to provide energy for only one winter night and a portion of the following day (King 1972). Winter habitat selection thus becomes a hunt for nocturnal roosts that permit minimal energy expenditures (Walsberg 1985), and it is not surprising that cold "snaps" cause high mortality (Kessler *et al.* 1967). If, as the evidence suggests, MASS bird communities consist mostly of resident cavity-roosting birds, then this raises the question of how logging may influence the availability of thermally suitable nocturnal roost sites. Determining the extent of use of the harvested MASS area by birds in winter will provide important results concerning how and whether different logging methods influence bird communities in winter.

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Montane Alternative Silvicultural Systems (MASS) Forest Structure and Natural Vegetation Dynamics

*William Beese, Jeff Sandford and Judith Toms
MacMillan Bloedel Limited
65 Front Street
Nanaimo, B.C. V9R 5H9*

Introduction

This project is one of several focussed on investigating aspects of silvicultural systems being compared at the MASS study area in coastal montane forests. Clearcutting, Green Tree Retention, Shelterwood and Patch Cutting create different forest structure and microclimates that may affect natural regeneration and vegetation succession.

The literature review completed for the MASS project summarized our current knowledge of advanced regeneration, natural seed-in and competing vegetation in montane forests of the Coastal Western Hemlock zone of B.C., and relevant neighboring areas in the Pacific Northwestern U.S. (Koppenaar and Mitchell 1992).

Objectives

The objective of this study is to characterize and quantify the effects of Clearcutting, Green Tree Retention, Patch Cutting and Shelterwood silvicultural systems on natural vegetation dynamics.

Specific objectives are:

1. To determine the age distribution of trees in all canopy layers and size classes in the study area before treatment;
2. To describe the species composition, size class distribution, canopy structure and health of trees retained in partial cutting systems (Green Tree Retention, Shelterwood);
3. To quantify and compare conifer seed rain in Old Growth and under four silvicultural systems;
4. To quantify and compare the growth and survival of natural conifer regeneration, both advanced and seed-in, in response to four silvicultural systems;
5. To quantify and compare understory vegetation species composition and cover in response to four silvicultural systems, and four sub-treatments (herbicide, fertilizer, herbicide+fertilizer, and untreated).

Methods

Nine 500 m² plots were established in the Clearcut, Green Tree and Patch Cut treatments after harvesting to determine the age distribution within the old growth stand by size class for 130 trees over 5 cm diameter. Growth rings were counted on about 20 to 25 stumps per plot: 4 trees each in 5–10, 11–20, 21–40, and 41–60 cm diameter classes, and all trees over 60 cm. Because of logging damage to smaller stems, the age of advance regeneration under 5 cm in basal diameter

was determined from 200 trees sampled adjacent to permanent vegetation plots in each treatment. Disks were taken from each tree for sanding and ring counting in the lab. Previous studies by the author indicate that field counts cannot be done with sufficient accuracy because of extremely small annual rings on many trees (Beese, unpublished report).

Pre-harvest forest inventory at about three times the normal intensity for a commercial timber cruise was done in November 1991 and April 1992. Sample plots included information collected during a standard MacMillan Bloedel Operational Cruise (tree heights and diameters by species, tree form and decay class, site and vegetation features, etc.), plus supplementary observations. Field crews recorded stand structure, understory regeneration, and dead standing trees (snags) and downed woody material by decay class (Bartels *et al.* 1985) and three DBH classes: <30 cm, 30 to 60 cm, and >60 cm. Stand tables and a 1:5000 scale map were prepared. For the post-harvest inventory, all standing trees were measured in the Green Tree blocks. The Shelterwood blocks were sampled with six standard cruise plots per block.

Vegetation cover, height and species composition within treatments and untreated Old Growth were measured before and after harvesting in each of three "core" replicates established within all five silvicultural treatments. Eighteen permanent plots were established in each replicate, for a total of 270 plots. Twelve plots were located in seedling response plots (three per treatment). Another six plots were located within the growth and yield Permanent Sample Plot (PSP). Each plot consisted of a series of nested plots. Visual estimates of vegetation cover by strata, life form and species were recorded on a 12.6 m radius (500 m²) plot. Only trees from 1.3–10 m in height were included, because forest cover inventory characterized larger size classes. A 2 m × 5 m plot was located at a random bearing from the centre of the circular plot to estimate cover of shrubs and small trees (<1.3 m tall). Cover of herbs and mosses was assessed on a 1 m × 2 m plot within the larger plot.

Advanced regeneration was counted by species, height and basal diameter classes on the same plots as the understory vegetation. Trees less than 30 cm were tallied on the 1 m × 2 m plot as either seedlings or germinants; trees from 30 cm to 1.3 m were tallied on the 2 m × 5 m plot. Up to three amabilis fir (*Abies amabilis*) and western hemlock (*Tsuga heterophylla*) were tagged and measured after harvesting, and will be measured periodically on each plot. Damage to advanced regeneration from harvesting was assessed by recording surviving trees, and noting stem and foliage damage.

A series of seed collection traps were established in conjunction with the vegetation and natural regeneration plots to monitor conifer seed-in. Three, 0.25 m² circular wire frames with screen collection bags, based on a design by Hughes *et al.* (1987), were placed 1 m above the ground within the growth and yield PSP in each treatment replicate. Screens were emptied annually in September, November and May. Seed counts and germination tests were conducted in the MacMillan Bloedel Forest Sciences Laboratory.

Results and Discussion

Forest Age

Most of the amabilis fir at the MASS study area were under 250 years old, with some trees up to 500 years old. Western hemlock, however, had a more normal distribution, with trees ranging in age from 200 to 800 years old (Figure 1). There were many individuals in the 400 to 500 year age class. Yellow-cedar (*Chamaecyparis nootkatensis*) and western redcedar (*Thuja plicata*) covered a

similar range to that of western hemlock. The oldest tree in the sample plots was a yellow-cedar estimated at over 800 years old. Advance regeneration samples showed that small trees typically ranged from 25 to 150 years old. The oldest understory tree sampled was a 207-year-old western hemlock with a diameter of 4 cm.

Tree ages, stand structure and the presence of charcoal at the mineral soil surface under 10 to 40 cm of forest floor suggest that this stand has developed in the absence of fire disturbance or large-scale windthrow for at least 500 years, and probably much longer. Only a few scattered Douglas-fir (*Pseudotsuga menziesii*) veterans were found in the pre-harvest inventory. The north aspect, the mosaic of well-drained and moist soils, and the elevation also suggest that fires on this site would be infrequent and discontinuous.

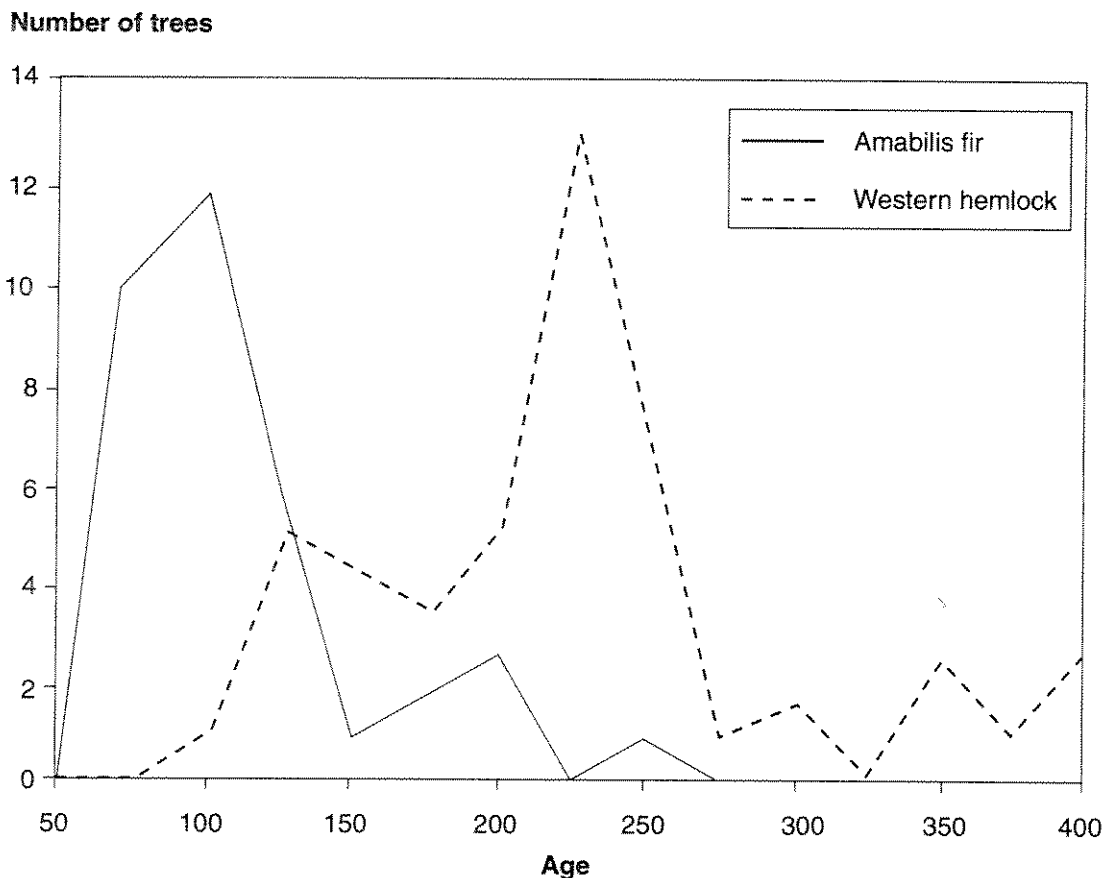


Figure 1. Age distribution of overstory trees at the MASS study area.

Forest Stand Characteristics

Pre-harvest

Pre- and post-harvest stand characteristics for the Green Tree Retention (GT) and Shelterwood (SW) blocks are summarized in Table 1. Although species composition varied among treatment blocks, western hemlock typically comprised 40% of the volume. Most of the remaining volume was amabilis fir. The proportion of western redcedar and yellow-cedar varied from 10 to 30 percent. Average gross merchantable volume ranged from 911 to 1,159 m³/ha among SW and GT treatment blocks, with total net volumes of 499 to 757 m³/ha due to decay and breakage factors. Overall, there were about 500 stems per hectare over 17.5 cm DBH. Average tree height for the hemlock and fir was 24 to 32 metres. The redcedar and yellow-cedar were generally 10 m taller and twice the average diameter of the western hemlock and amabilis fir.

Table 1. Pre-and post-harvest forest characteristics for the Green Tree Retention and Shelterwood treatments

	Green Tree		Shelterwood	
	Pre	Post	Pre	Post
Species Composition (by basal area):				
Western hemlock	44	51	43	49
Amabilis fir	24	15	29	33
Western redcedar	28	28	24	17
Yellow-cedar	5	5	4	1
Gross merchantable volume (m ³ /ha)	1038	47	975	172
Percent of gross volume retained		5		18
Net merchantable volume (m ³ /ha)	723	n/a	553	148
Basal area (m ² /ha)	86	4	73	18
Percent basal area retained		5		25
Stems per hectare (over 17.5 cm DBH)	599	22	494	206
Average stand height (m)	25	23	28	18
Average diameter (cm at 1.3 m)	41	40	45	32
Understory trees (sph>1.3 m tall, <17.5 cm DBH)	560	n/a	569	300
Seedlings (<1.3 m tall, % cover)	28	n/a	31	19
Snags per ha	78	0	80	0

Understory trees in all areas were predominantly amabilis fir. Approximately 70 to 80% of the basal area from trees greater than 1.3 m tall but less than 17.5 cm DBH was amabilis fir; the remainder was western hemlock. These trees were typically 2 m to 10 m tall, with average diameters of 6 to 10 cm. Density varied among areas from 600 to 763 stems per hectare. Advance regeneration less than 1.3 m tall was also dominated by amabilis fir. Average cover of amabilis fir ranged from 18 to 21 percent among areas, while western hemlock ranged between 7 and 10 percent. Only minor amounts of redcedar and yellow-cedar occurred in the understory.

There was considerable variability in the total number of snags among treatments. The Old Growth had the fewest number of snags (52 sph) and the Clearcut had the greatest (100 sph). The number of large (>60 cm) snags was more similar, with the fewest number in the alternative treatment blocks (28 sph) and the greatest in the Old Growth (39 sph). Half of the study area average of 80 snags per hectare were natural stumps; one-third were either their full height but free of bark and limbs, or with broken tops and in various stages of decomposition; the remaining 16% were more recent snags with intact bark and limbs. Hemlock snags predominated, with 65% to 70% of the stems in each size class. Most of the remainder were amabilis fir, with a small percentage of

western redcedar and yellow-cedar snags. Nearly half of the snags were in the 30 cm to 60 cm diameter class, and over one-third were greater than 60 cm in diameter. Average heights for the <30 cm, 30 cm to 60 cm and >60 cm diameter classes were 20 m, 32 m and 39 m, respectively.

There was an average of 17 to 34 downed stems per hectare, which was fairly evenly distributed among the three size classes. The clearcut had higher amounts than the rest of the study area.

Post-harvest

After losses to logging damage and windthrow, 83% of the target basal area remained standing in the SW, and 88% of the target stems per hectare remained standing in the GT blocks (Table 1). The incidence of parasitic dwarf mistletoe on western hemlock was reduced from 18% in the original stand to 6% in the SW and 3% in GT through selection of leave trees (see paper by Nevill and Wood in these proceedings). The proportion of net merchantable volume in the residual stand was also improved from 57% to 86% in the SW through removal of decayed trees. Species composition after harvesting remained similar to pre-harvest conditions for both treatments. In the GT, treatment increased the proportion of western hemlock relative to amabilis fir. Both of these species increased in the Shelterwood, with a corresponding decrease in the proportion of western redcedar and yellow-cedar.

The remaining trees were representative of the original stand profile; consequently, over half of the stems were in the intermediate crown class. Many of these trees are amabilis fir with healthy crowns that should respond well to release. These same trees would contribute little value to harvest revenues, yet will provide protection for regeneration and a significant starting volume for the next rotation. Roughly one-quarter of the Shelterwood leave trees and about one-third of the Green Tree Retention trees were in the dominant and codominant crown classes.

Windthrow

Windthrow was assessed in the Shelterwood and Green Tree treatments in August, 1994, nine months after completion of harvesting. A complete post-harvest inventory was done on downed trees in the Green Tree and Shelterwood treatments. Data collection included: height, diameter, height to crown, crown class, direction of fall, presence of marking paint, soil moisture and depth, scarring or other damage, and probable cause of damage. After reviewing the extent of windthrow, MacMillan Bloedel decided not to salvage any of the trees. Windthrow was relatively light and scattered, making salvage difficult without disturbing research installations.

Windthrow was summarized for Shelterwood and Green Tree Retention (Table 2). Counts do not include trees blown down during harvesting that were subsequently salvaged. An average of 14% of the trees were damaged by wind in the Green Tree treatment, with little variation between replicate blocks. Most of the trees were uprooted, but some had broken tops or were severely leaning. In the Shelterwood, an average of 4% of the reserve trees blew down. Although windthrow was a smaller proportion of the leave trees in the Shelterwood, it represented three times as many trees per hectare. An assessment of windthrow in the Old Growth, Clearcut and Patch Cut treatments will be done in 1995.

Table 2. Windthrow in MASS Green Tree Retention (GT) and Shelterwood (SW) replicates (November 1993 to August 1994)

	Area (ha)	Understory ¹	Leave Trees ²		Windthrow ³			Standing
		<17.5 cm	>17.5 cm	t/ha	Total	t/ha	%	t/ha
Green Tree Retention								
GT 1	8.6	8	180	21	33	3.8	18	17
GT 2	9.7	48	228	24	33	3.4	14	20
GT 3	9.0	32	282	31	33	3.7	12	27
Total	27.3	88	690		99			
Average	9.1	29	230	25	33	3.6	14	22
Shelterwood								
SW1	9.4	—	2060	219	105	11.2	5	208
SW2	9.5	—	2273	239	77	8.1	3	232
SW 3	8.7	—	1618	186	74	8.6	5	178
Total	27.6	—	5951		256			
Average	9.2	—	1983	216	85	9.3	4	206

¹ Understory trees <17.5 cm DBH in GT replicates are "extra" trees left, but not included in the 25 t/ha merchantable target during marking. A few represent trees just under 17.5 cm judged visually as merchantable during marking. All calculations of trees per hectare and windthrow are based on stems >17.5 cm only.

² Total standing and down from post-harvest inventory. For the Shelterwood replicates, standing trees were estimated by multiplying the average stems per hectare for all three blocks calculated from inventory plots by the proportion of total trees in each block counted on aerial photographs.

³ Trees windthrown during harvesting and subsequently yarded are not included.

The pattern of direction of windfall observed is consistent with storms from predominantly two directions: northwest and southeast (Figure 2). These directions are typical of strong storms on the coast (Stathers *et al.* 1994). Wind speed and direction data supplied by J. Senyk and D. Craigdallie from the Canadian Forest Service from the weather station in the neighboring clearcut showed that 85% of the maximum wind events were equally divided between two primary directions: west to northwest (265° to 310°) and east to southeast (105° to 150°). This correlated positively with the predominant direction of windfall; however, patterns of windfall varied among replicate blocks due to protection from neighboring Old Growth.

The intermediate crown class contained the highest number and proportion (22%) of windthrown trees in the Green Tree treatment. Other crown classes had less than 10% windthrow. Although the Shelterwood treatment had the greatest number of fallen trees in the intermediate class, the proportion (9%) was lower than the suppressed class (18%). The higher percentage of fallen suppressed trees was partially due to trees knocked over by other trees. High windfall mortality in the intermediate class in the more open Green Tree Retention is consistent with the fact that these

trees were sheltered from winds before harvesting; consequently, they had not developed adequate root systems for stability in the open. In addition, their tall, narrow stems and short, flat crowns increased sway forces. Greater wind protection in the Shelterwood may be the cause of the lower proportion of windthrown intermediates relative to the Green Tree treatment.

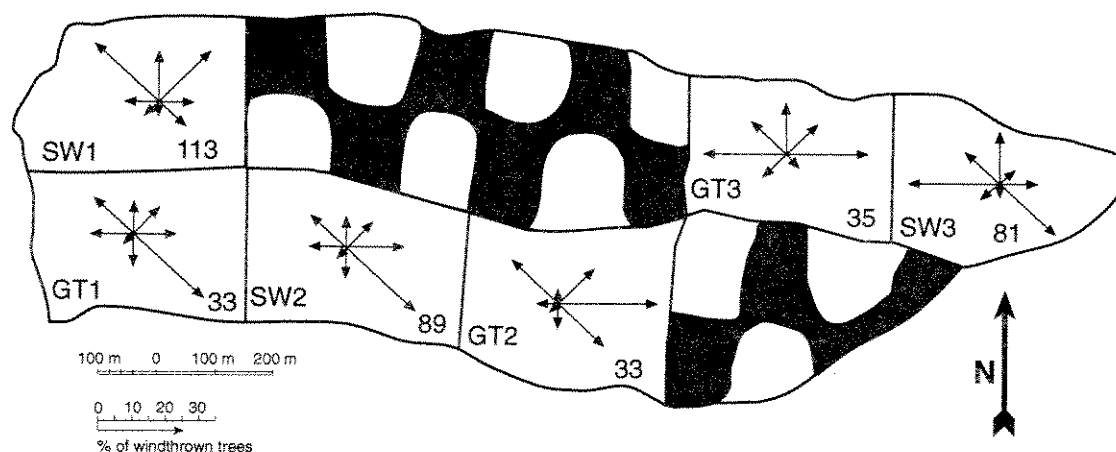


Figure 2. Orientation and number of windthrown trees at MASS during the first 9 months after harvesting – November 1993 through August 1994. Arrow size is proportional to the number of trees windthrown in that direction; number of trees windthrown is given in the lower right corner of each treatment replicate.

Seedfall

Seed collected from the forest floor underneath the seed traps was combined with the fall 1993 collection up to November 25 (Fall, Table 3). The forest floor collection consisted of the seed bank from previous years, plus seedfall before the traps were installed. The amount of seed collected in Fall was lower than that collected between November and September (Winter–Spring, Table 3). The distribution of seed by species and treatment was consistent between the two collection periods. In the Fall collection, total seedfall in the Old Growth was significantly greater than in the Clearcut, Patch Cut, Green Tree and Shelterwood treatments. None of the partial cutting treatments were significantly different from the Clearcut or each other.

Hemlock seeds were more common than western redcedar, amabilis fir and yellow-cedar in both the Fall and Winter-Spring collections ($p \leq 0.01$). Western redcedar seeds were more abundant in the Winter–Spring collection compared to yellow-cedar and amabilis fir ($p < 0.1$). The number of hemlock seeds, as a proportion of total seedfall, decreased from the Clearcut (97.9%) to the Old Growth (69.7%). Very little amabilis fir and yellow-cedar seed was collected.

Germination rates for all species were very low. Germination for the November and May collections was 26 to 44% for hemlock and considerably less for amabilis fir (2 to 14%), western redcedar (12 to 28%) and yellow-cedar (0 to 9%). Seedtrap samples had significantly higher germination rates than forest floor samples ($p < 0.01$). Germination rates did not vary between the Old Growth and other treatments.

Table 3. Total seedfall by treatment in the Fall and Winter–Spring collection periods

Trt ³	Fall ^a			Winter–Spring ^b			Total	
	Average seeds / m ²	SE		Average seeds / m ²	SE		Average seeds / m ²	SE
CC	8.44	2.75	a	56.00	3.59	a	64.44	6.35
PC	116.89	38.18	a	484.00	115.86	a	600.89	154.04
GT	140.00	49.92	a	313.33	122.37	a	453.33	172.29
SW	152.00	85.48	a	822.22	415.19	a	974.22	500.67
OG	501.78	255.86	b	4439.56	1094.82	b	4941.33	1350.68

^a Forest floor and collection up to November 25, 1993.

^b Collection between November 26, 1993 and September 1, 1994.

^c Treatments are: CC = Clearcut, PC = Patch Cut, GT = Green Tree Retention, SW = Shelterwood, OG = Old Growth.

Natural Conifer Regeneration

Pre- and post-harvest counts of germinants, seedlings (less than 30 cm tall) and understory trees (less than 1.3 m tall) showed no statistically significant differences as a result of treatment or season; however, the general trend for both western hemlock and amabilis fir in all harvested blocks suggested that there were one quarter to one half as many trees, seedlings and germinants after treatment. The exception to this trend was amabilis fir in the Shelterwood, where about two-thirds of the trees and seedlings survived, and the number of germinants appeared to be higher after harvesting.

Trends in the Old Growth revealed some insights about the relationship between seed production, germination and survival as understory trees. Amabilis fir had the greatest number of understory trees at 2,000 per hectare. There were 25 times as many amabilis fir seedlings, and nearly as many germinants as seedlings. The single year 1993/94 collection of over 100,000 seeds per hectare illustrates the substantial investment in seed production for each established understory tree, considering the multiple seed years involved in establishing the present cover.

Western hemlock had roughly one thousand trees, 40 to 75 thousand seedlings and up to 1 million germinants per hectare. Hemlock seedfall for the one year collection was about 34 million seeds per hectare; consequently, the ratio of seeds to germinants to established seedlings is extremely high. Western redcedar data showed even higher mortality from seed to seedling; it had less than one tree, 250 to 500 seedlings and 1,200 to 5,000 germinants per hectare compared to a one-year seedfall of nearly 14 million seeds. Although the laboratory germination rate of western redcedar was similar to western hemlock and amabilis fir, its forest survival is extremely low. Factors that probably contribute to its low establishment rate in the Old Growth understory include low light levels, lack of exposed mineral soil substrate, interception of seed by thick moss cover, predation and competition from other vegetation. Old Growth trends also suggested that there was substantial variation in the annual number of hemlock germinants, and that some mortality of hemlock seedlings occurred.

Understory Vegetation

Understory vegetation on the study area is dominated by Alaskan blueberry (*Vaccinium alaskaense*), oval-leaved blueberry (*V. ovalifolium*) and mosses (*Rhytidiadelphus loreus*, *Hylocomium splendens* and *Rhytidiopsis robusta*). Herbaceous cover occurs mostly on moist to wet microsites and consists of foamflower (*Tiarella trifoliata*), rosy twisted stalk (*Streptopus roseus*), several ferns and occasional skunk cabbage (*Lysichiton americanum*).

The cover, frequency and number of species of understory plants decreased after harvesting in all treatments. The Shelterwood maintained greater cover of understory trees, shrubs and mosses compared to the other systems (Figure 3). Understory vegetation was protected from damage by the excavator and skidder within the undisturbed clumps of leave-trees. The shade provided in the Shelterwood has allowed mosses to survive at over half of their original cover of 71%, in contrast to the three more open treatments where mosses were reduced to 10% cover or less. Although the sparse herbaceous cover was reduced in the first season after harvesting, it is expected to increase in subsequent years due to invasion of disturbance colonizers such as fireweed, common groundsel and wall lettuce. Shrubs are expected to increase rapidly from resprouting of live roots that survived harvesting.

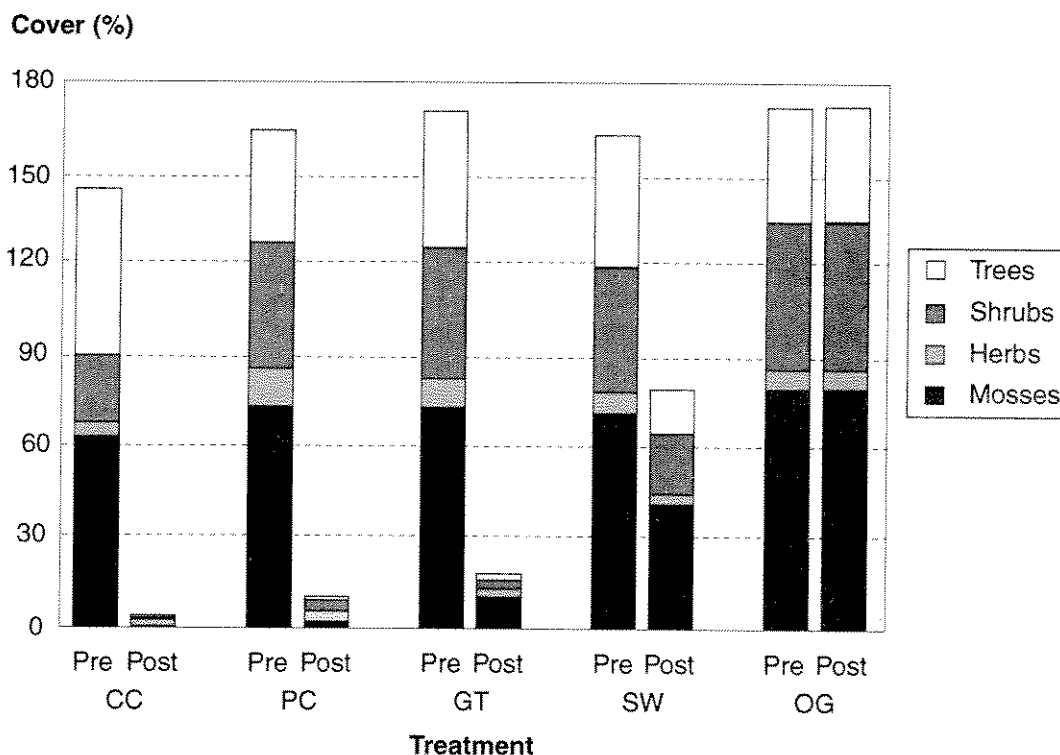


Figure 3. Cover of understory vegetation by life form before and after harvesting.

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