Salal Cedar Hemlock Integrated Research Program

Research Update #2: Silvicultural Practices for Regeneration of Cedar-Hemlock Sites in Coastal British Columbia

Edited by

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Background

The Salal Cedar Hemlock Integrated Research Program (SCHIRP) was initiated in the early 1980s in response to concerns of foresters about inadequate regeneration of sites dominated by salal (*Gaultheria shallon*) on northern Vancouver Island. About 5-8 years after clearcutting and slashburning old-growth forests on cedar-hemlock (CH) sites (Plate 1), the growth of planted Sitka spruce (*Picea sitchensis)* and naturally regenerated western hemlock (*Tsuga heterophylla*) slowed, and needles showed signs of chlorosis (Plate 3). The growth problem was not as apparent in western redcedar (*Thuja plicata*). These indications of severe nutrient deficiency coincided with vigorous reinvasion of CH sites by the ericaceous shrub salal. Trees established on adjacent hemlock-amabilis fir (HA) cutovers (Plate 2) did not exhibit this growth check.

Initially, SCHIRP was a collaboration between Dr. John Barker, then of Western Forest Products Ltd. (WFP) and Dr. Gordon Weetman of the Faculty of Forestry at the University of British Columbia (UBC). A series of trials was established in the early 1980s to determine if the poor regeneration on CH sites could be attributed to low nutrient supply and thus could be alleviated by fertilization. Plot Fertilization Trials were established on CH cutovers to test the effects of various combinations of nutrients on the growth of Sitka spruce (est. 1983), western redcedar and western hemlock (est. 1987). This was followed by the Salal Removal and Fertilization Trial of 1984, testing several various combinations of nutrient addition and manual and chemical salal removal were tested. In 1987, the Pine as Nurse Species Trial was established to examine the potential for lodgepole pine (*Pinus contorta* var. *contorta*) and white pine (*Pinus monticola*) to act as a nurse species for Sitka spruce.

In 1988, SCHIRP expanded to include partners from MacMillan Bloedel Ltd. (now Weyerhaeuser), TimberWest (now Norske Skog), the Canadian Forest Service (CFS), the BC Ministry of Forests, and the faculties of Forestry and Agricultural Sciences at UBC. This phase of SCHIRP was funded by the Natural Sciences and Engineering Research Council of Canada and the industrial partners. The SCHIRP Installation was established on northern Vancouver Island in 1988 to test the effects of scarification, fertilization and establishment density on redcedar and hemlock regeneration on CH and HA sites. Several ecological studies were undertaken to explore the underlying causes of differences between CH and HA sites. Additionally, a series of Organic Fertilization Trials was established in 1989.

Beginning in 1995, SCHIRP was funded by Forest Renewal BC. New initiatives in this phase included establishment of a second SCHIRP Installation on western Vancouver Island by Weyerhaeuser (1996), fertilization at planting and scarification trials on CH-HA transition sites by WFP (1996), a series of fertilization at planting trials on CH sites by WFP and Weyerhaeuser (1996), a salal fertilization trial by UBC (1998), vegetation and fertilization trials on high-elevation *Vaccinium* sites by CFS (1998), and establishment of a trial with nutrient-loaded hemlock seedlings by CFS (2000). Ecological studies completed during this phase improved our understanding of the nitrogen and phosphorus nutrition of several species, the mycorrhizae of salal, salal tannins, and forest succession.

Findings from the many SCHIRP silvicultural trials were made available in reports published by the Faculty of Forestry at UBC in 1994 and 1996. A list of all current publications based on SCHIRP research is included at the end of this report. SCHIRP publications and information are also available on the SCHIRP website (www.forestry.ubc.ca/schirp/homepage.html).

In this report, we present the most recent findings from eleven key silvicultural trials that have been established and maintained under the SCHIRP program. Like all SCHIRP reports, this is the result

of research efforts by several individuals from several institutions. Key contributors to this report are Annette Van Niejenhuis of Western Forest Products, Bill Beese of Weyerhaeuser and John Barker, Jennifer Bennett, Karen Bothwell and Gordon Weetman of the Faculty of Forestry, UBC. John Barker, Paul Bavis, Bill Beese, Annette van Niejenhuis, David Haley, Brian Titus and Gordon Weetman are acknowledged for reviewing the report.

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Plot fertilization trials

Single-tree fertilization trials in Sitka spruce and western redcedar on CH cutovers indicated that chlorosis and slow growth could be alleviated by fertilization with nitrogen (N) and phosphorus (P). Plot trials were then established in young, slow-growing plantations of Sitka spruce, western hemlock and western redcedar on CH cutovers to estimate the long-term gains in productivity that could be realized with different combinations and rates of nutrient addition. All sites were clearcut and slashburned prior to planting.

Research Trials

Sitka Spruce

- **Location:** near Port McNeill
- **Site:** CH
- **Tree species:** planted *Picea sitchensis*
- **Year established:** 1983
- **Tree age at establishment:** 9 years
- **Treatments:**
  - 0N 0P (control)
  - 100N 50P (100 kg/ha N and 50 kg/ha P)
  - 200N 50P
  - 300N 50P
  - 300N 150P
  - 300N 50P + micronutrient mix
- **Number of replicates:** 3
- **Variables measured:** height, diameter at 0.1 m, diameter at 1.3 m (DBH), foliar nutrients

N was applied as ammonium nitrate and P as triple superphosphate. The micronutrient mix provided (in kg/ha) 38 P, 91 K, 56 Ca, 48 Mg, 31 S, 1.8 Fe 0.3 B, 0.72 Zn, 0.3 Cu, 0.75 Mn, and 0.2 Mo.

Western Redcedar

- **Location:** near Port McNeill
- **Site:** CH
- **Tree species:** planted *Thuja plicata*
- **Year established:** 1987
- **Tree age at establishment:** 7 years
- **Treatments:** all 12 combinations of the following N and P dosages:

0N	0P
100N	100P
200N	100P + micronutrient mix
300N	

- **Number of replicates:** 3
- **Variables measured:** height, diameter at 0.1 m, DBH, foliar nutrients

N was applied as urea and P as triple superphosphate. The micronutrient mix provided (in kg /ha) 99 P, 102 K, 129 Ca, 51 Mg, 50 S, 9 Fe, 3.5 Mn, 1.5 Cu, 1.5 B and 1.0 Mo.

Western Hemlock

- **Location:** near Port McNeill
- **Site:** CH
- **Tree species:** planted *Tsuga heterophylla*
- **Year established:** 1987
- **Tree age at establishment:** 7 years
- **Treatments:** all 12 combinations of the following N and P dosages:

0N	0P
100N	100P
200N	100P + micronutrient mix
300N	

- **Number of replicates:** 3
- **Variables measured:** height, diameter at 0.1m, DBH, foliar nutrients

N was applied as urea and P as triple superphosphate. The micronutrient mix provided (in kg /ha) 99 P, 102 K, 129 Ca, 51 Mg, 50 S, 9 Fe, 3.5 Mn, 1.5 Cu, 1.5 B and 1.0 Mo.

Findings

Sitka Spruce

Fertilization significantly improved spruce growth (Table 1, Table 3). The greatest response was in plots that received 300N and 150P, where the average volume was 10 times greater than in control plots after 14 years (Table 1). Fertilization with 100 kg/ha N and 50 kg/ha P increased volume by a factor of four (Table 1). At 300N, the trees fertilized with 150P were outperforming those fertilized with 50P, indicating that 50 kg/ha P did not completely alleviate P deficiency. There was no additional growth from the micronutrient mix; the heights and diameters of trees receiving micronutrients (N300+P50+micronutrient mix) were not significantly different from trees fertilized with either N200+50P or N300+50P. One year after treatment, fertilized trees also had greener foliage, larger needles, and higher foliar nutrient concentrations (Table 2). Foliar P levels were still significantly elevated 14 years after fertilization (0.10% in 300N+150P and 300N+50P+mix plots and 0.08% in 0N+0P plots), whereas N concentrations had declined to pre-fertilization levels. Foliar K concentrations declined to below adequate in trees fertilized with 300N.

During the two years after treatment, unfertilized spruce trees grew about 6 cm/year, while spruce trees fertilized with 300N+150P grew about 40 cm/year. Between 7 and 14 years after fertilization, trees treated with 300N+150P still had significantly (p<0.10) greater height growth than control trees (Figure 1, Table 3). The difference in total stand volume also increased from year 6 to 14. These results indicate that a single fertilization treatment increases spruce growth for at least 7 years.

Fertilization of spruce on northern Vancouver Island may increase weevil (*Pissodes strobi*) attack. One growing season after fertilization, weevils had damaged significantly more trees in plots receiving 300N+150P than in control plots. However, during the four years after fertilization, trees that had been fertilized and attacked by weevils still outgrew trees that had not been fertilized.

Western Hemlock

Height, diameter, and volume of hemlock trees were significantly increased by fertilization with N and P (Table 1, Table 3). Responses were less in plots fertilized with 100N+100P or with 300N+0P. There was no significant difference between trees fertilized with 100P and those fertilized with 100P + micronutrients. Fertilization with high levels of N+P increased stand volume nearly 7 times over controls. During the three years after fertilization, annual height growth in plots that received the high N+P additions was about 80 cm compared with about 15 cm in control plots. Addition of P appears to have resulted in a prolonged height response, as evident in the increasing difference between fertilized and control plots between years 4 and 11 (Figure 1, Table 1, Table 3).

Table 1. Stand characteristics of 23-year-old Sitka spruce fertilized at 9 years, 18-year-old western hemlock fertilized at 7 years, and 18-year-old western redcedar fertilized at 7 years. Volume was calculated using total heights and diameter at breast height (DBH) (Millman, 1976). Seven-year height growth is between 7 and 14 years after fertilization for Sitka spruce and between 4 and 11 years after fertilization for western redcedar and western hemlock. Only a subset of treatments is shown.

Fertilization treatment	DBH (cm)	Total height (m)	Total stand volume (m^3/ha)	7-year height growth (m)
Sitka spruce				
Control (no fertilizer)	4.2	2.8	1.0	0.8
100N 50P	6.4	3.9	4.6	0.9
300N 50P	8.7	4.8	7.4	1.0
300N 150P	9.1	5.5	10.8	1.7
Western hemlock				
Control (no fertilizer)	3.4	3.1	2.2	1.1
100N 100P	6.2	4.7	8.9	1.7
300N 0P	5.2	4.1	5.8	1.1
300N 100P	7.5	5.3	14.6	1.8
300N 100P+micronutrients	8.2	5.6	16.4	2.1
Western redcedar				
Control (no fertilizer)	6.3	4.9	9.1	2.7
100N 100P	7.4	5.3	14.5	2.8
300N 0P	8.0	5.4	17.1	2.8
300N 100P	8.5	5.9	22.5	3.3
300N 100P+micronutrients	8.4	6.1	24.7	3.3

Foliar N and P concentrations in control plots were well below those considered adequate for hemlock (Table 2). One year after treatment, fertilization had raised N concentrations to adequate levels, but P concentrations were still less than adequate. While N levels declined within a few years after fertilization, P levels remained elevated 11 years after fertilization (foliar P concentrations were 0.15% in plots treated with 100P, and 0.07% in plots receiving no P). Although foliar K concentrations were below adequate levels in trees fertilized with N and P, the lack of additional growth response to the addition of micronutrients indicates that K was not limiting.

Western Redcedar

Total volume of cedar at 18 years was greater than that of hemlock or spruce, for both unfertilized and fertilized treatments. Unfertilized cedars grew 30-40 cm/year, which was twice that of unfertilized hemlock. Cedar was not as responsive to fertilization as spruce or hemlock; its height growth increased to 45-55 cm/year for the three years following high N+P additions. Fertilization with 100N+100P increased volume, and fertilization with 300N+100P doubled stand volume 11 years after fertilization (Table 1). Addition of the micronutrient mix did not significantly increase growth. Although the height growth of cedar between 4 and 11 years after fertilization was not significantly increased

References

Table 2. Foliar nutrient concentrations (%) of 10-year-old Sitka spruce and 8-year-old western hemlock and western redcedar one growing season after fertilization, and foliar nutrient concentrations considered adequate (Ballard and Carter 1986). Only a subset of treatments is shown.

	Nutrient concentration (%)		
	N	P	K
Sitka spruce			
Adequate level [1]	1.55	0.16	0.50
Control (no fertilizer)	0.69	0.13	0.70
100N 50P	2.96	0.21	0.52
300N 50P	3.93	0.22	0.45
300N 150P	3.99	0.24	0.48
Western hemlock			
Adequate level	1.45	0.35	0.80
Control (no fertilizer)	0.93	0.08	0.76
100N 100P	1.49	0.32	0.62
300N 0P	2.42	0.12	0.61
300N 100P	1.99	0.22	0.64
300N 100P + mix	1.82	0.20	0.74
Western redcedar			
Adequate level	1.65	0.16	0.85
Control (no fertilizer)	1.12	0.15	0.59
100N 100P	1.27	0.19	0.45
300N 0P	1.42	0.16	0.60
300N 100P	1.57	0.20	0.46
300N 100P + mix	1.64	0.22	0.64

[1] Adequate levels for Sitka spruce were not determined; values for white spruce are shown.

300N+P was greater than those fertilized with 300N only (Figure 1, Table 1). Future monitoring of these studies will determine if there is a prolonged response to P.

Cedar foliar N and P concentrations were increased by fertilization, but N concentrations remained below the adequate level in all treatments (Table 2). Foliar P levels were above adequate levels in trees that were fertilized with P after one year. Eleven years after fertilization with P there was still a small, but statistically significant increase in P concentrations (0.14% in plots receiving no P, and 0.16% in plots receiving P). Foliar K concentrations were below adequate levels in all treatments.

Conclusions

- Cedar produced the most volume on unfertilized and fertilized sites.
- Spruce and hemlock were very responsive to fertilization with N and P.
- Additions of N+P significantly increased growth of all three species. Additions of more than 100 kg/ha N + 50 kg/ha P produced the greatest growth, hence fertilization with 200 kg/ha N and 100 kg/ha P is recommended.
- There was no additional growth in response to the micronutrient mix.
- P fertilization appeared to prolong the growth response of spruce and hemlock but not cedar.
- Foliar P concentrations of all species remained elevated 11 and 14 years after fertilization, indicating that a second application of P may not be necessary.

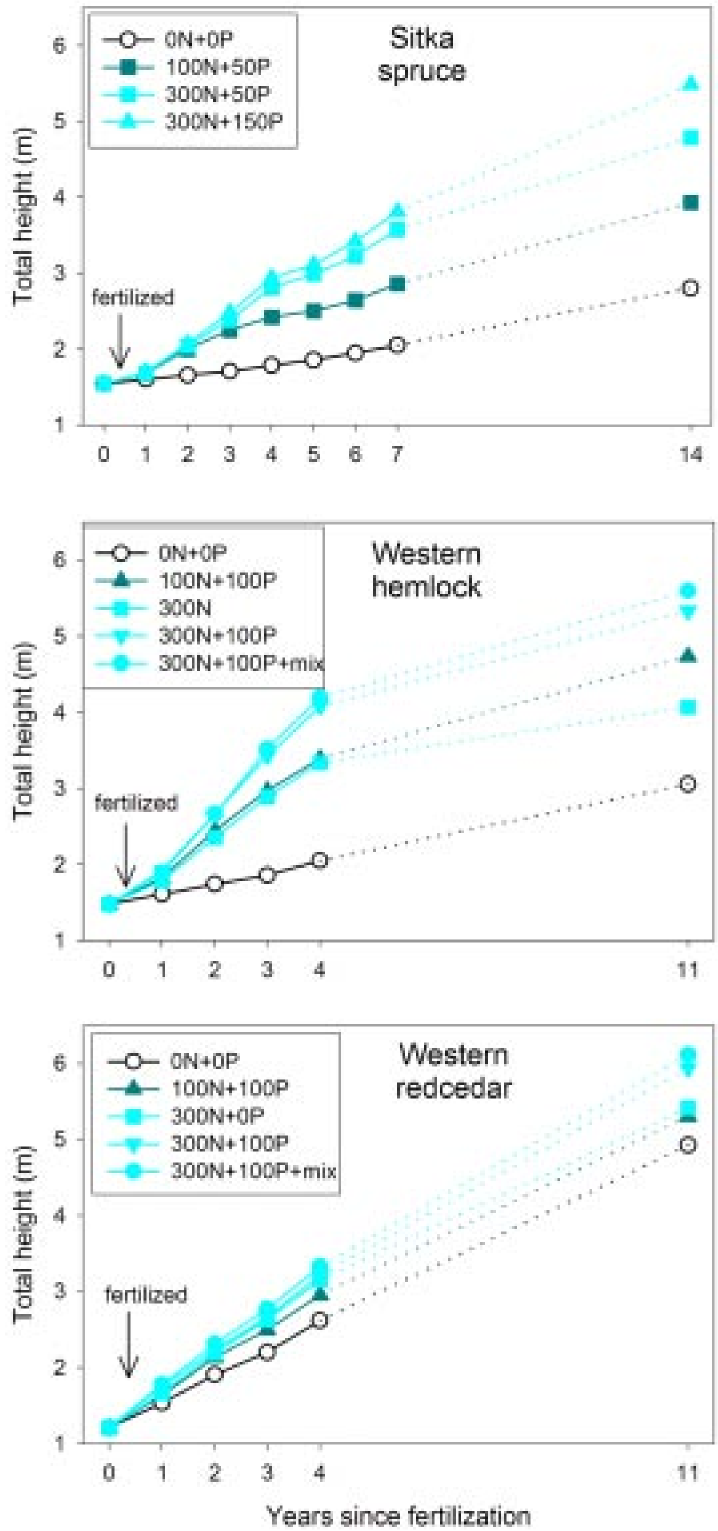

Figure 1. Height of 23-year-old Sitka spruce fertilized at 9 years, 18-year-old western hemlock fertilized at 7 years, and 18-year-old western redcedar fertilized at 7 years. Only a subset of treatments is shown.

Table 3. Analysis of variance table for 23-year-old Sitka spruce fertilized at 9 years, 18-year-old western hemlock fertilized at 7 years, and 18-year-old western redcedar fertilized at 7 years. Heights and diameter at breast height values are for planted trees. Stand volume values are for planted trees plus volunteers. Seven-year height growth is between 7 and 14 years after fertilization for Sitka spruce and between 4 and 11 years after fertilization for western redcedar and western hemlock. Height before treatment was used as a covariate for height, DBH and volume but was not significant for height growth. Interaction refers to N fertilization and P fertilization. Significant effects (p<0.05) are bolded.

	p-value			
	DBH	Total height	Total stand Volume	7-year height growth
Sitka spruce				
Block	**0.0466**	**0.0105**	**0.0404**	0.1533
Fertilization	**0.0001**	**0.0001**	**0.0029**	0.0829
Initial height	**0.0005**	**0.0004**	**0.0131**	--
Western hemlock				
Block	**0.0172**	**0.0097**	0.2113	**0.0128**
N Fertilization	**0.0001**	**0.0001**	**0.0011**	**0.0177**
P Fertilization	**0.0001**	**0.0001**	**0.0110**	**0.0001**
Interaction	0.0796	0.0531	0.3432	0.1581
Initial height	**0.0002**	**0.0004**	**0.0223**	--
Western redcedar				
Block	**0.0002**	**0.0195**	0.5832	**0.0085**
N Fertilization	**0.0094**	**0.0169**	0.0606	0.1259
P Fertilization	0.1501	0.0765	0.0651	0.1087
Interaction	0.6616	0.9592	0.9970	0.7182
Initial height	**0.0003**	**0.0001**	**0.0021**	--

References

Ballard, T.M. and R.E. Carter. 1986. *Evaluating Forest Stand Nutrient Status*. Land Mange. 20, British Columbia Ministry of Forests, Victoria, 60 pp.

Millman, M. 1976. Metric volume and V-bar tables derived from the BCFC whole stem cubic metre volume equations. Vancouver, B.C.

3

The salal removal and fertilization trial

The nutrient deficiencies and resulting poor growth of regenerating conifers on CH sites may be a consequence of either poor nutrient supply or competition from salal. This trial was installed to test the relative efficacy of salal removal and fertilization in accelerating crown closure of conifers on CH sites.

Research Trial

- **Location:** near Port McNeill
- **Site:** CH
- **Tree species:** planted *Picea sitchensis*; *Tsuga heterophylla* and *Thuja plicata* volunteers
- **Year established:** 1984
- **Tree age at establishment:** 9-15 years (spruce)
- **Treatments:** all 12 combinations of the following:

0N (control)	0P (control)	no salal removal
250N urea	100P	salal removal
250N ammonium nitrate		

- **Number of replicates:** 5
- **Variables measured:** height, DBH

Salal was removed with Pulaski axes in the first growing season (1984), and herbicide (Garlon 4E) was applied at the end of the second and fifth growing seasons after establishment. Fertilizers were broadcast applied once, at the beginning of the second growing season.

Heights of the planted Sitka spruce were measured prior to treatment and annually for the first four growing seasons following treatment. Fourteen growing seasons after treatment, heights and diameters of all trees taller than 1.3 meters were measured. This included substantial numbers of naturally regenerated western redcedar, western hemlock and a few lodgepole pine.

Findings

During the four years following treatment, salal removal, N fertilization, and P fertilization significantly improved spruce height growth (p=0.0001 for all three treatments) (Figure 2). Where N and P were added together the trees responded more than where either element was added alone (p=0.0001 for the interaction of N and P). The largest increases in height were in the salal removal plus N+P fertilization plots. There was no height difference between the urea and ammonium nitrate treatments after 4 years so only the ammonium nitrate plots were measured at 14 years. Spruce showed continued growth response to fertilization between years 4 and 14 (p<0.08) (Figure 2), with the plots that received both fertilization (N+P) and salal removal showing the largest continued response.

Total stand volume at fourteen years (including volunteer cedar, hemlock and lodgepole pine) and the volume of hemlock and spruce was significantly increased by fertilization and salal removal (p<0.01 for fertilization and p<0.01 for salal removal). The two treatments combined increased total conifer volume from the control level of approximately 37 m^3/ha to 122 m^3/ha 14 years after treatment. Hemlock and spruce responded more to fertilization than to salal removal alone (Table 4, Table 5), but the

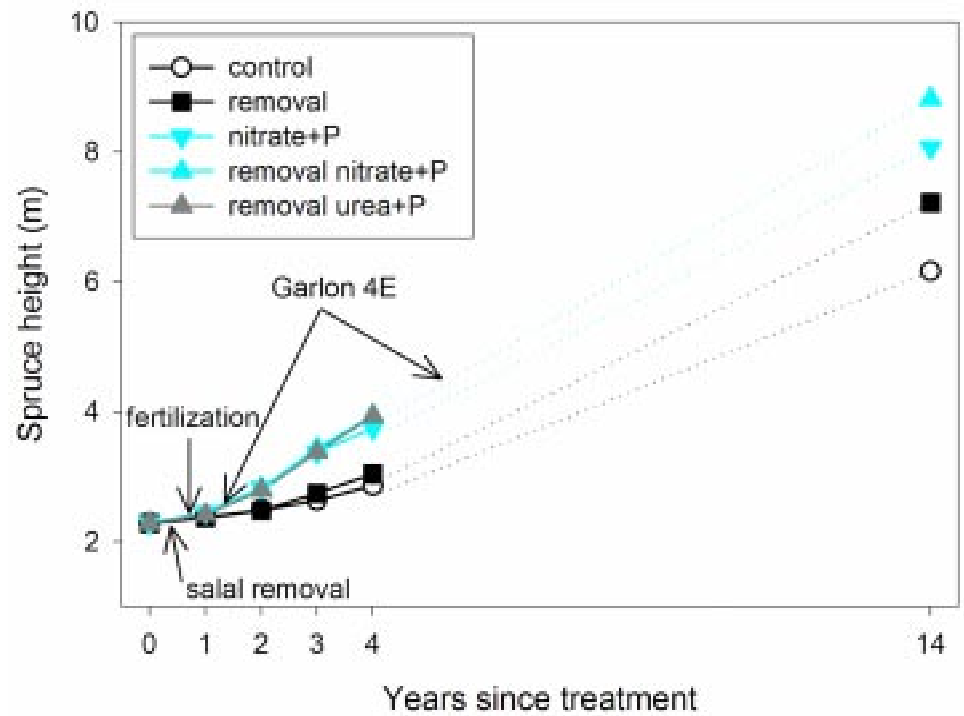

Figure 2. Height of planted Sitka spruce after fertilization and removal of salal. Treatments were no fertilization or salal removal (control), removal of salal (removal), fertilization with 250 kg N/ha as ammonium nitrate and 100 kg P/ha (nitrate+P), both removal of salal and the above fertilization treatment (removal+nitrate+P), and removal of salal and fertilization with 250 kg N/ha as urea and 100 P kg/ha (removal+urea+P). There was no height difference between the urea and ammonium nitrate treatments after 4 years so only the ammonium nitrate plots were measured at 14 years.

greatest response was to the combined treatment. Cedar produced more volume than either spruce or hemlock in control plots (Table 4), and responded more to salal removal than fertilization (Table 5).

Conclusions

- Fertilization with N+P and salal removal improved growth of the planted spruce and the volunteer hemlock. For all three species, the greatest growth was in plots that received both treatments.
- Spruce and hemlock responded to both salal removal and fertilization, although the response to fertilization was slightly greater.
- Cedar grew much better on untreated sites than spruce or hemlock and responded significantly only to salal removal.
- There was no difference in height response of spruce to fertilization with urea or ammonium nitrate, so either N form can be used to fertilize CH sites.

Table 4. Average height, diameter and volume of planted Sitka spruce and volunteer western hemlock and western redcedar 14 years after N+P fertilization and salal removal. Volume was calculated using the equation for a cone. For each species, different letters indicate significant differences between treatments (p<0.05).

	Total Height (m)	DBH (cm)	Volume (m^3/ha)
Sitka Spruce			
Control	6.2 a	6.9 a	7.5 a
Salal removal only	7.2 ab	9.0 a	29.4 ab
N+P only	8.1 bc	9.9 ab	36.3 ab
Removal + N+P	8.8 c	12.5 b	55.2 b
Western Hemlock			
Control	5.4 a	5.0 a	6.0 a
Salal removal only	7.1 ab	6.5 ab	10.8 a
N+P only	7.9 ab	7.5 b	20.0ab
Removal + N+P	9.0 b	8.8 b	33.4 b
Western Redcedar			
Control	6.7 a	8.2 a	20.1 a
Salal removal only	8.0 ab	10.5 a	39.8 a
N+P only	7.2 ab	8.6 a	26.1 a
Removal + N+P	8.6 b	10.3 a	31.6 a

Table 5. Analysis of variance table for planted Sitka spruce and volunteer western hemlock and western redcedar 14 years after N+P fertilization and salal removal. Values from the most recent measurement year were tested. Interaction refers to fertilization and salal removal. Significant effects (p<0.05) are bolded.

	p-value		
	Total Height	DBH	Volume/ha
Sitka Spruce			
Block	**0.0151**	**0.0095**	**0.0040**
Fertilization (N+P)	**0.0041**	**0.0082**	**0.0322**
Salal removal	**0.0345**	**0.0009**	0.0945
Interaction	0.7418	0.7753	0.8977
Western Hemlock			
Block	0.5021	0.0943	0.5888
Fertilization (N+P)	**0.0078**	**0.0012**	**0.0029**
Salal removal	0.0684	**0.0364**	0.0895
Interaction	0.6740	0.8675	0.4023
Western Redcedar			
Block	**0.0339**	**0.0072**	**0.0004**
Fertilization (N+P)	0.1998	0.7952	0.8394
Salal removal	**0.0066**	**0.0062**	**0.0349**
Interaction	0.9481	0.6312	0.2098

4

Pine as a nurse species for improving the growth of Sitka spruce

On nutrient-poor sites dominated by ericaceous plants in Britain and Ireland, pine or larch are often planted as "nurse species" for Sitka spruce. Planting spruce in mixture with pine or larch results in enhanced growth and foliar N content of Sitka spruce. The mixture effect becomes apparent 8-10 years after stand establishment. This trial was established to test if intimate mixtures with lodgepole pine or western white pine would improve the growth and nutrition of Sitka spruce on CH sites.

Research Trial

- **Location:** near Port McNeill
- **Site:** CH
- **Tree species:** planted *Picea sitchensis*, *Pinus contorta* var. *contorta*, *Pinus monticola*
- **Year established:** 1988
- **Tree age at establishment:** 0 (stand established as part of experiment)
- **Treatments:** the following mixtures planted at 2, 2.6, and 3 m spacing (9 treatments):
  - Spruce planted alone
  - Spruce interplanted with white pine
  - Spruce interplanted with lodgepole pine
- **Number of replicates:** 3
- **Variables measured:** 10-year total height, 1-year height increment, root collar diameter, foliar nutrient concentrations

In all plots, Sitka spruce was planted in a 6 x 6 tree grid. In the mixed plots, a pine was planted between each spruce, such that each spruce was surrounded by four pine neighbors.

Findings

There were no significant differences in the height, diameter, or annual height increment of Sitka spruce planted in pure plots or mixed with either pine species at any planting density (Table 6, Plate 5). Height of the 10-year-old spruce averaged 1.4 m, and root collar diameter was 25 cm. Foliar nutrient concentrations in spruce were below what is considered to be adequate, regardless of treatment (Table 7). Thus, there was no evidence of a nursing effect of pine on spruce growth or nutrition.

However, there was a striking difference between the growth of lodgepole pine and the other species (Figure 3, Plate 4). Lodgepole pine was more than 2.5 times taller than spruce. The average height of the 10-year-old lodgepole pine was 3.7 m, and RCD was 68.7 cm. Foliar concentrations of N and P in lodgepole pine were adequate (Table 7).

The reasons for the better growth and nutritional status of lodgepole pine were examined in a related study (Bothwell *et al*. 2001). Pine clearly accessed more N during the 10 years, as the above-ground N content of lodgepole pine trees (determined by biomass and N concentration) was 9 times greater than that of Sitka spruce. The greater N uptake by pine may be related to the presence of some mycorrhizal fungal associates on roots of pine but not spruce that are capable of taking up N in organic forms. Pine was also more efficient with N, produc-

Table 6. ANOVA table for 10-year-old Sitka spruce planted alone or in mixture with western white pine or lodgepole pine. Height increment is the difference between 9- and 10-year heights.

	p-value		
	Height	RCD	Height increment
	2 m spacing		
Treatment (interplanting)	0.5102	0.5474	0.3372
	2.6 m spacing		
Treatment (interplanting)	0.3832	0.1436	0.3317
	3 m spacing		
Treatment (interplanting)	0.5052	0.3206	0.4660

ing much more biomass per unit N, producing less foliage, and removing a greater proportion of the N from needles prior to shedding. Forest floors in lodgepole pine plots were also better aerated, which may contribute to improved N supply.

Conclusions

- Interplanting spruce with either western white pine or lodgepole pine did not improve spruce growth or nutrition after 10 years.
- Lodgepole pine had substantially better growth and foliar N concentrations than Sitka spruce on CH sites.

References

Binns, W.O., G.J. Mayhead, and J.M. Mackenzie. 1980. Nutrient deficiencies of conifers in British forests. For. Commn. Leafl. No. 76. HMSO, London.

Bothwell, K.S., C.E. Prescott, and M.D. Jones. 2001. Factors contributing to the superior growth and N nutrition of 11-year-old lodgepole pine compared to Sitka spruce on a N-poor cedar-hemlock cutover. Can J. For. Res. 31: 1272-1279.

Everard, J. 1973. Foliar analysis: sampling methods, interpretation and application of results. Quart. J. For. 68: 51-66.

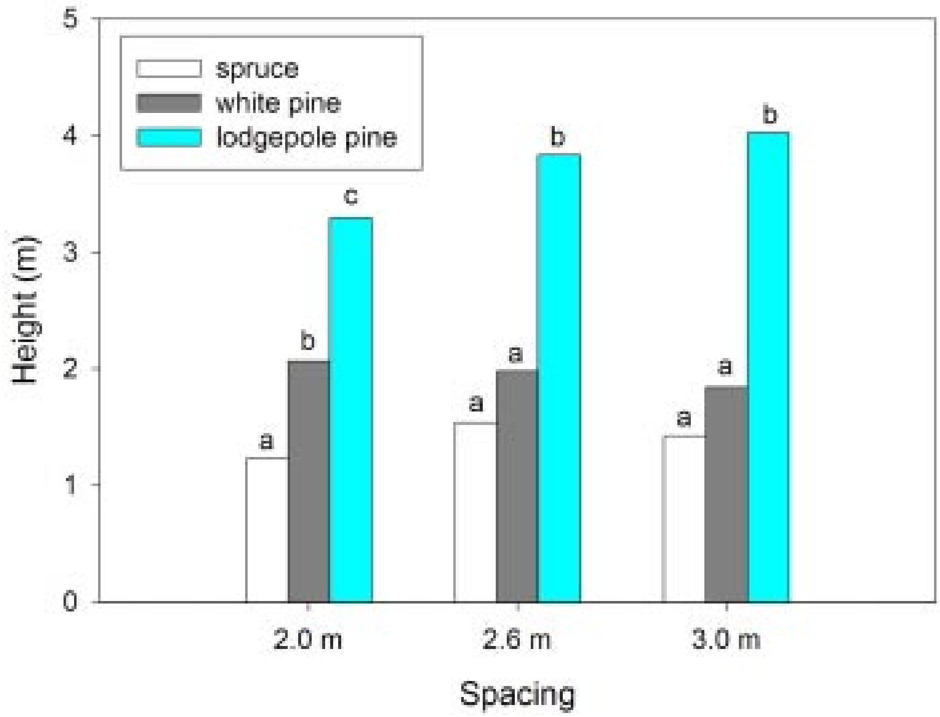

Figure 3 . Average height of Sitka spruce, western white pine, and lodgepole pine at three spacings in the nurse trial. The height and diameter of spruce were the same whether planted alone or in mixture with either pine species; therefore only one mean for each spacing is presented. Within a spacing, different letters indicate significant height differences between species (p<0.05).

Table 7. Foliar nutrient concentrations (%) of Sitka spruce and lodgepole pine on the CH cutover compared with deficient and adequate levels from Everard (1973) and Binns *et al.* (1980).

	Observed	Adequate
Nitrogen		
Sitka spruce	0.72-0.86	1.2
Lodgepole pine	1.04-1.12	1.0
Phosphorus		
Sitka spruce	0.12-0.17	0.18
Lodgepole pine	0.13-0.15	0.12

5

Organic fertilization trials

Fertilization trials have demonstrated that conifers on CH sites are responsive to additions of N and P. Municipal biosolids (sewage sludge) are rich in N and P, and impressive growth responses have been reported following the application of municipal biosolids to many forests. Biosolids may also promote a longer growth response than inorganic fertilizers as the nutrients are released more gradually. Another potential organic fertilizer in coastal B.C. is fish silage produced from fish farm waste, which is high in N and other nutrients, but is acidic. Wood ash could be mixed with fish silage to make it less acidic. Pulp sludge could be used to increase the carbon content of biosolids or fish silage and thus slow the release of N. Two trials were established in 1989 to test the efficacy of a variety of organic fertilizers for improving growth of conifers on CH cutovers.

Research Trial

Trial One

- **Location:** near Port McNeill
- **Site:** CH
- **Tree species:** planted *Thuja plicata*, *Tsuga heterophylla*, *Abies amabilis*
- **Year established:** 1990
- **Tree age at establishment:** 9 years
- **Treatments:**
  Control (unfertilized)
  Biosolids: 542 kg N/ha and 162 kg P/ha as sewage sludge (69 Mg/ha)
  N+P: 225 kg N/ha and 75 kg P/ha as ammonium nitrate and triple superphosphate
- **Number of replicates:** 4
- **Variables measured:** Total height, height increments between 2-3 and 3-4 years after treatment

Dewatered, anaerobically digested biosolids from the Greater Vancouver Regional District were rewatered on site and manually sprayed onto the plots. The higher loading of N in the biosolids was designed to compensate for less of the N being in readily available forms. Height increments were measured for 5 years to assess the duration of the response.

Trial Two

- **Location:** near Port McNeill
- **Site:** CH
- **Tree species:** planted *Thuja plicata*
- **Year established:** 1990
- **Tree age at establishment:** 9 years

- **Treatments:**
  - Control (unfertilized)
  - Biosolids: 542 kg N/ha and 162 kg P/ha as sewage sludge
  - Biosolids+pulp: 610 kg N/ha as sewage sludge mixed with pulp sludge
  - Fish silage+ash: 504 kg N/ha as fish silage mixed with wood ash
  - Fish silage+pulp+ash: 504 kg N/ha Fish silage and ash mixed with pulp sludge
  - Ash: 5 Mg/ha of wood ash alone
  - N+P: 225 kg N/ha and 75 kg P/ha as ammonium nitrate and triple superphosphate
- **Number of replicates:** 3
- **Variables measured:** Total height, height increments between 2-3 and 3-4 years after treatment

Pulp mill clarifier sludge was added to the biosolids and to the silage to increase the C:N ratio of the fertilizers. Wood ash has very low N concentrations (0.08%) but contains many micronutrients and has a high pH, which increased the pH of the silage. Height increments were measured for 5 years to assess the duration of the response.

Findings

Trial One

Both biosolids and N+P fertilizer significantly increased the height growth of all three species (response of amabilis fir is shown in Figure 4 and Plate 6). There were no significant differences in height growth between trees treated with biosolids and those treated with N+P fertilizer, indicating that there was no difference in tree response between N+P and organic fertilizer. Height increments of all three species in N+P fertilized and biosolids-amended plots during years 4 and 5 were much reduced from those during years 2 and 3, but were still significantly greater than in control plots (Figure 4). Salal growth also increased following fertilization with biosolids or N+P fertilizer.

Trial Two

All of the organic amendments (except wood ash alone) stimulated height growth of western redcedar (Figure 5). Height increments during years 2 and 3 were significantly greater in plots treated with N+P fertilizer, biosolids or fish silage (alone or amended with pulp sludge) than in control plots or plots treated with wood ash (Figure 5). Height growth during years 4 and 5 declined in all plots treated with N+P fertilizer or organic amendments. There were no significant differences in responses to the various organic and N+P treatments during years 4 and 5. In control trees and in trees treated with wood ash, height growth in years 4 and 5 increased relative to years 2 and 3. As in Trial One, salal was stimulated by both organic and N+P fertilization.

In the fish silage treatments, the organic material had been ground and ensiled in formic acid for several weeks prior to application, so would have been largely broken down prior to application. Most of the N in the silage was thus, probably available immediately after application. Foliar N concentrations were greater in the fish silage treatments than any other treatment during the first two years after application, despite similar application rates (McDonald *et al*. 1994), indicating that fish silage supplied more mineral N than did biosolids in the first year or two after application.

However, the additional N released from silage did not result in significantly greater height growth, suggesting that the cedar on these sites do not respond to N additions greater than 250 kg/ha.

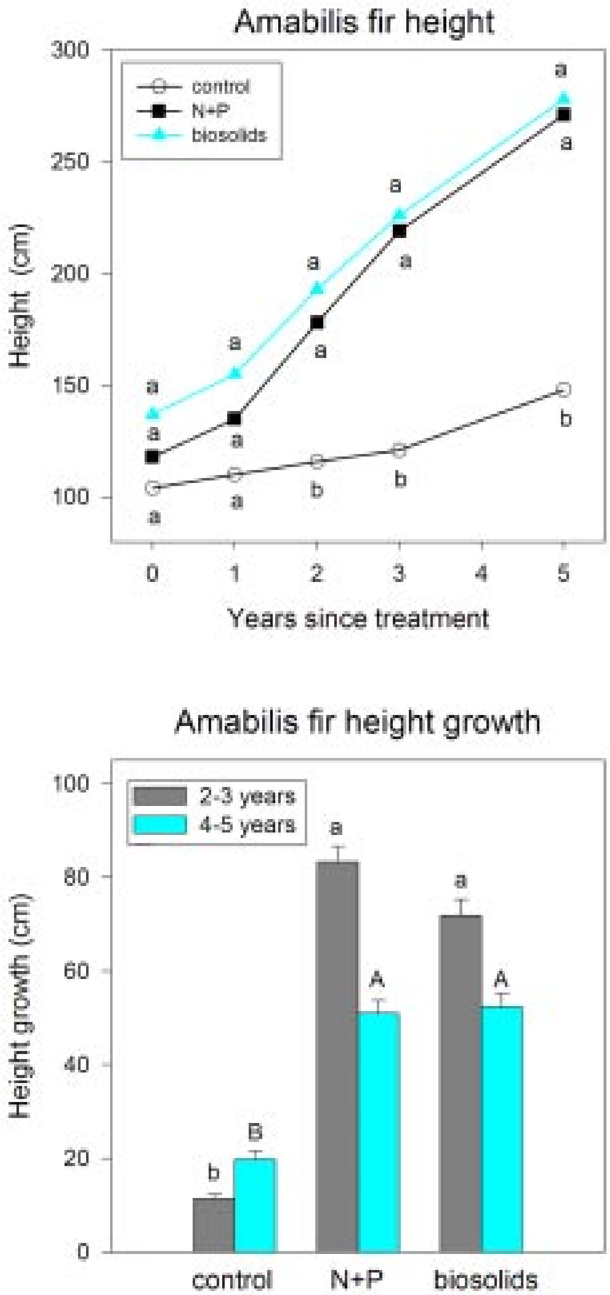

Figure 4. Amabilis fir total height and height growth during years 2 and 3 and during years 4 and 5 after fertilizer application (Trial One). The mean and standard error of the four plots of each treatment are shown. For each year, different letters indicate significant differences between treatments.

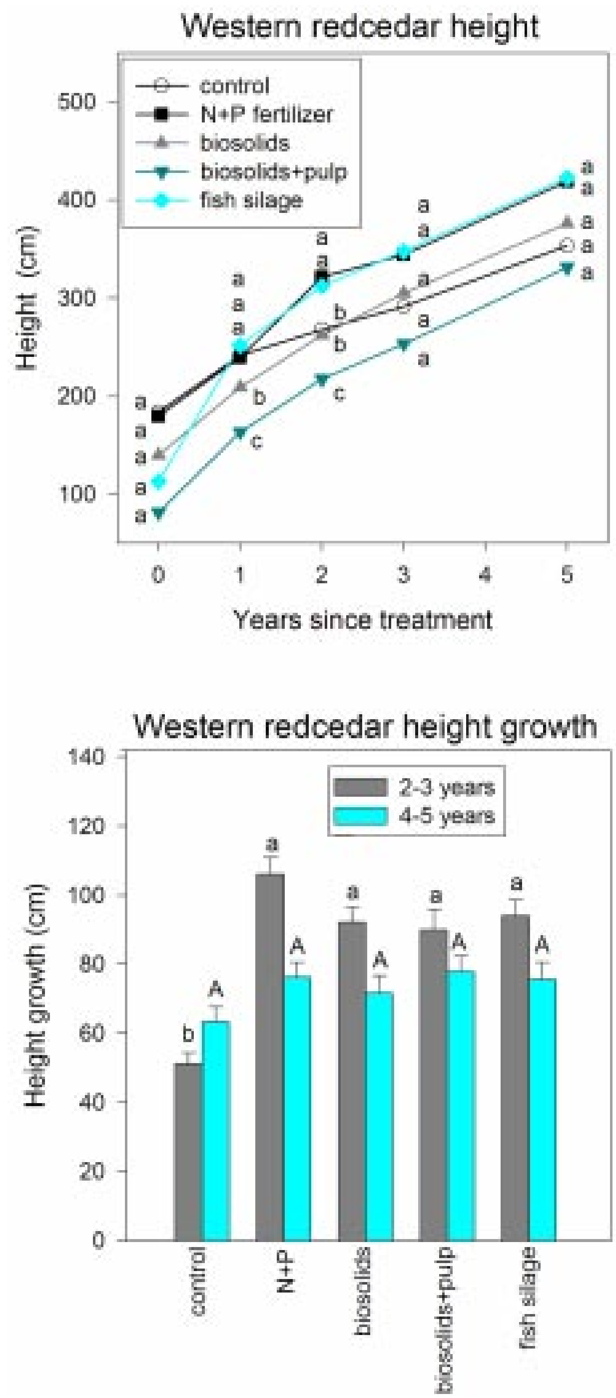

Figure 5. Western redcedar total height and height growth during years 2 and 3 and during years 4 and 5 after fertilizer application (Trial Two). Because ash had no effect on tree growth, the two treatments containing ash are not shown. The mean and standard error of three plots per treatment are shown. For each year, different letters indicate significant differences between treatments.

Conclusions

- All organic amendments except wood ash increased growth of conifers.
- The growth responses to the organic amendments were similar both in magnitude and duration to those achieved with N+P fertilizer, indicating that release of N from the biosolids was mostly confined to the first one or two growing seasons.
- There was no evidence that the addition of pulp sludge to the biosolids and fish silage caused N to be released more gradually.
- Although more than twice as much N was added in the biosolids, the response was the same as that achieved by adding 225 kg N ha^{-1} in ammonium nitrate.
- Salal growth was stimulated by both organic and chemical fertilizers.

Further Reading

Weetman, G.F., M.A. McDonald, C.E. Prescott, and J.P. Kimmins, 1993. Responses of western hemlock, Pacific silver fir, and western redcedar plantations on northern Vancouver Island to applications of sewage sludge and inorganic fertilizer. Can. J. For. Res. 23:1815-1820.

McDonald, M.A., B.J. Hawkins, C.E. Prescott, and J.P. Kimmins, 1994. Growth and foliar nutrition of western redcedar fertilized with sewage sludge, pulp sludge, fish silage and wood ash on northern Vancouver Island. Can. J. For. Res. 24:297-301.

Prescott, C.E. and S.M. Brown, 1998. Five-year growth response of western redcedar, western hemlock, and amabilis fir to chemical and organic fertilizers. Can. J. For. Res. 28:1328-1334.

6

The SCHIRP installation

The SCHIRP installation was established to determine the best management practices for hastening crown closure on CH cutovers. Responses of both cedar and hemlock to scarification and repeated fertilization were compared on both CH and HA sites.

Research Trial

- **Location:** near Port McNeill
- **Site:** CH and HA
- **Tree species:** planted *Tsuga heterophylla* and *Thuja plicata*
- **Year established:** 1987/1988
- **Tree age at establishment:** 0 (stand was established as part of trial)
- **Treatments:** all combinations of the following:

no scarification	no fertilization (control)	western hemlock
scarification	repeated fertilization	western redcedar

- **Number of replicates:** 4
- **Variables measured:** height, basal diameter, DBH

The experiment was established in the winter of 1987/88. Scarification was completed with a 215 Cat Excavator backhoe with a 3-tyned rake attachment. Cedar and hemlock container stock seedlings (1+0 313 PSB) were planted at 2500 stems/ha on both site types. Plots also were established at 500 and 1500 stems/ha (and fertilized or not), but establishment density is not expected to be important until the stands reach crown closure. For this reason, only one planting density (2500 stems/ha) is presented here. Fertilizer was applied at the time of planting around each tree. Sixty grams of Nutricote™ slow-release fertilizer were raked into the ground within 15 cm of each seedling. The fertilizer dose per tree was 10 g N, 2.5 g P, and 5 g K. The fertilized plots were re-fertilized in 1993 with a broadcast application of 225 kg N/ha and 75 kg P/ha. Volume was calculated using the volume equation for a cone and total height and basal diameter.

Findings

CH sites

On CH sites, the largest response was in plots where scarification and fertilization were applied together (Figure 6). The two tree species responded to the treatments in slightly different ways. For cedar, heights and diameters of fertilized trees were larger than unfertilized trees, but scarification had only a small effect on height and diameter (Table 8, Plate 8). The increases in height and diameter resulted in greater cedar volume where either treatment was applied (Table 9). For hemlock, scarification and fertilization significantly increased height, diameter and volume (Table 9, Plate 7). Hemlock volume response to fertilization was enhanced by scarification (Table 9). The primary goal of scarification was to reduce the amount of salal by damaging its roots. The reduction of salal cover may have increased fertilizer availability to hemlock.

Table 8. Mean heights and diameters of 10-year-old trees and mean stand volume of western hemlock and western redcedar planted on CH and HA sites. Trees were fertilized at planting and at 6 years. For each site type and species, different letters indicate significant differences between treatments (*p*<0.05).

CH sites

	DBH (cm)	Height (m)	Stand Volume (m^3/ha)
Western Hemlock			
Control	0.7 a	1.5 a	0.7 a
Scarification	1.7 a	2.4 a	4.8 a
Fertilization	4.8 b	4.4 b	20.0 b
Scarification+fertilization	6.5 c	5.6 c	37.9 c
Western Redcedar			
Control	2.6 a	2.8 a	6.6 a
Scarification	3.3 ab	3.2 ab	13.5 a
Fertilization	4.5 ab	3.8 ab	19.1 ab
Scarification+fertilization	6.1 b	4.7 b	37.3 b

HA sites

	DBH (cm)	Height (m)	Stand Volume (m^3/ha)
Western Hemlock			
Control	5.1 a	4.8 a	31.3 a
Scarification	6.4 ab	5.6 a	36.8 ab
Fertilization	9.5 a	7.4 a	85.6 b
Scarification+fertilization	9.1 ab	7.1 a	74.4 ab
Western Redcedar			
Control	3.2 a	2.8 a	11.8 a
Scarification	4.6 ab	3.8 ab	21.6 ab
Fertilization	6.9 bc	5.0 b	45.7 b
Scarification+fertilization	7.1 c	5.0 b	46.3 b

The trees benefited from both fertilization at the time of planting (*p*<0.05 for cedar volume and *p*<0.01 for hemlock volume at year 5) and fertilization after the fifth year. Five years after stand establishment and fertilization at planting, average hemlock heights were 2.3 m in scarified and fertilized plots and 1 m in control plots. Cedar heights were 2 m in scarified and fertilized and 1.4 m in control plots at five years. After 10 years and a second fertilization, cedar stand volume was 5.7 times greater, and hemlock volume was 54 times greater than untreated controls (see CH Figure 6).

HA sites

On HA sites, conifer growth was significantly improved by fertilization (Figure 6), but not scarification (Table 9). The benefit of fertilization at planting on HA sites is unclear. At five years, cedar was significantly (*p*=0.02) taller in fertilized plots (2.0 m) than in control plots (1.6 m), but hemlock was 3.2 m tall in control and fertilized plots. These small differences indicate that nutrients do not strongly limit conifer growth on HA sites during the first few years following clearcutting.

Although hemlock did not respond to fertilization at planting, it appeared to be responsive to the second application of fertilizer. This can be seen in the

Table 9. ANOVA tables for planted western hemlock and western redcedar on CH and HA sites 10 years after establishment. Interaction refers to scarification and fertilization. Significant effects ($p<0.05$) are bolded.

CH sites

	p-value		
	DBH	Height	Volume/ha
Western Hemlock			
Block	0.3811	0.3463	0.3382
Scarification	**0.0025**	**0.0005**	**0.0014**
Fertilization	**0.0001**	**0.0001**	**0.0001**
Interaction	0.2990	0.4055	**0.0189**
Western Redcedar			
Block	0.8831	0.8995	0.7669
Scarification	0.0909	0.1201	**0.0304**
Fertilization	**0.0038**	**0.0056**	**0.0049**
Interaction	0.4706	0.5510	0.2808

HA sites

	DBH	Height	Volume/ha
Western Hemlock			
Block	0.2421	0.3330	0.2286
Scarification	0.6426	0.7327	0.8016
Fertilization	**0.0022**	**0.0092**	**0.0026**
Interaction	0.3257	0.3790	0.4714
Western Redcedar			
Block	0.0683	0.0745	0.0756
Scarification	0.1851	0.1387	0.3513
Fertilization	**0.0002**	**0.0007**	**0.0004**
Interaction	0.3200	0.1888	0.4057

divergence in volume on unfertilized and fertilized plots beginning in year 7 (see HA Figure 6). Cedar also responded to the second fertilization. At 10 years, cedar volume was 16.7 m^3/ha in the unfertilized plots (control and scarified only) and 46.0 m^3/ha in the fertilized plots (fertilized only and fertilized+scarified). Hemlock volume was 34.0 m^3/ha in the unfertilized plots and 80.0 m^3/ha in the fertilized plots.

HA sites are typically considered to be productive sites, but this study indicates that productivity on these sites can be further improved by fertilization 5-10 years after stand establishment.

Conclusions

- On unfertilized CH sites, cedar performed better than hemlock.
- On CH sites, fertilization with N+P+K at the time of planting improved early conifer growth.
- On CH sites, scarification, which disturbed the roots of salal, and repeated fertilization with N and P improved productivity.
- On HA sites, fertilization at planting improved growth of cedar only.
- Scarification did not improve the productivity of HA sites.
- On HA sites, N+P fertilization 5-10 years after stand establishment improved both cedar and hemlock growth.

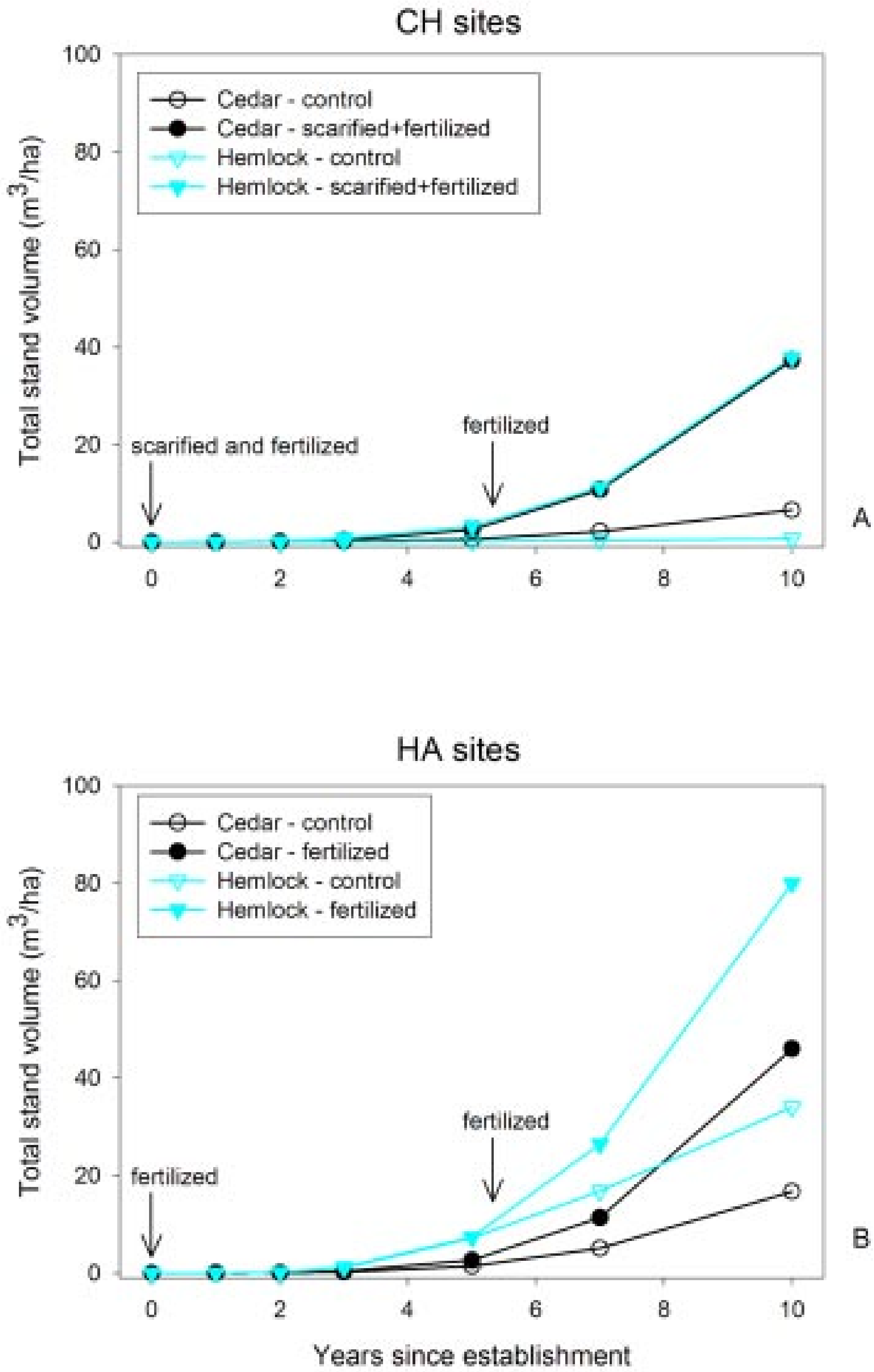

Figure 6. Total stand volume of 10-year-old hemlock and cedar plantations growing on CH and HA sites.

7

The Kennedy Lake trial

The effectiveness of fertilization and scarification for regenerating salal sites had been demonstrated in SCHIRP trials on northern Vancouver Island. However, it was not known if these treatments would be as effective on salal-dominated sites in other areas of coastal BC. A new trial modeled after the SCHIRP Installation was established at Kennedy Lake on the west coast of Vancouver Island by Weyerhaeuser Ltd.

Research Trial

- **Location:** east of Ucluelet
- **Site:** CH
- **Tree species:** planted *Tsuga heterophylla* and *Thuja plicata*
- **Year established:** 1995
- **Tree age at establishment:** 0 (stand was established as part of experiment)
- **Treatments:** all combinations of the following:

no scarification	no fertilization	western hemlock
scarification	fertilization	western redcedar
		50:50 mix of redcedar and hemlock

- **Number of replicates:** 3
- **Variables measured:** height, basal diameter, seedling condition, foliar nutrient concentrations, vegetative cover

A John Deere 640 excavator equipped with conventional pads and a 76-cm-wide rake was used for scarification. As with the trial on northern Vancouver Island, the primary objective of the scarification was to damage the salal rhizomes. Scarification also created a firm mineral soil mound elevated approximately 10 cm above the surrounding surface. Mounds were formed in a two-step process. First, debris and most of the humus were cleared in a "backhand" motion using the kickback teeth on the back of the rake. Then the rake would penetrate to approximately 20 to 30 cm depth, pulling and lifting to deposit mounded material on the edge of the scalp and undisturbed forest floor. Planting of PSB 315 stock at 1000 stems/ha was completed in March 1996. Additional plots of pure cedar and pure hemlock were established at 2000 stems/ha, but only results from the 1000 stems/ha plots are presented here. Fertilizer was applied at the time of planting by placing 28 g of granular fertilizer in a shovel hole 10 cm from the planted tree. The fertilizer delivered 7.3 g N and 7.0 g P/tree. This method differed from the SCHIRP Installation near Port McNeill in which granular fertilizer was applied on the ground around each tree and then raked into the upper surface layer.

Findings

Scarification successfully reduced the cover of the two dominant species, deer fern (*Blechnum spicant*) and salal (Figure 7, Plate 9). Vegetation cover in the scarified plots had doubled and was approaching that of the untreated plots. Salal cover in the scarified plots remained at about two-thirds the cover of salal in the untreated plots.

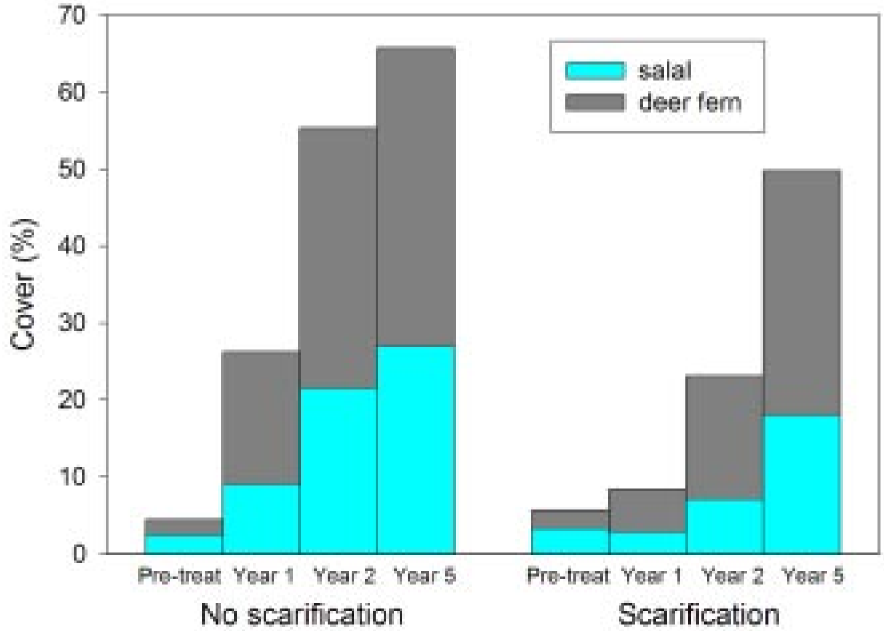

Figure 7. Development of salal and deerfern cover in scarified and unscarified plots. Vegetation cover was assessed before site preparation and 1, 2 and 5 years after treatment.

Plots with different mixtures were grouped to examine overall differences between fertilization, scarification, fertilization plus scarification, and controls. Differences in growth and foliar nutrition between mixed and pure plots are not likely to occur until trees are larger. This was confirmed with multiple means comparisons before pooling data.

At five years, cedar height increased in response to the combination of scarification and fertilization. Heights in control and treated plots were 101 cm and 185 cm, respectively. Cedar volume was significantly greater only in the combined treatment where tree volume was 10 times greater then in the control plots (Figure 8). Fertilization alone or in combination with scarification increased foliar N levels in cedar (Table 10) above adequate levels and P levels to near adequate. Western redcedar survival after 5 growing seasons was over 97%.

Hemlock height increased with both fertilization (Plate 10) and the combined treatments (Plate 11) but not with scarification alone. Average heights in control plots and in plots receiving the combined treatment were 91 cm and 174 cm, respectively. Individual tree volume of western hemlock was increased by fertilization alone and further increased by the combined fertilization and scarification treatment (Figure 8). Volume in plots that were scarified and fertilized was 13.5 times that of control plots. Fertilization alone or with scarification raised foliar N concentrations of hemlock above adequate levels (Table 10), but none of the treated hemlock approached adequate levels of P. Hemlock survival ranged from 65 to 85%.

Conclusions

- The combined treatment of scarification and fertilization at planting increased tree volume 10-fold, 5 years after planting. Scarification alone had a small effect on tree growth, while fertilization alone increased volume about 4-fold.

References

Prescott, C.E. and G.F. Weetman. 1994. Salal Cedar Hemlock Integrated Research Program: A Synthesis. Faculty of Forestry, University of British Columbia, 85 pp.

Ballard, T.M. and R.E. Carter. 1986. *Evaluating Forest Stand Nutirent Status.* Land Manage. 20, British Columbia Ministry of Forests, Victoria, B.C., 60 pp.

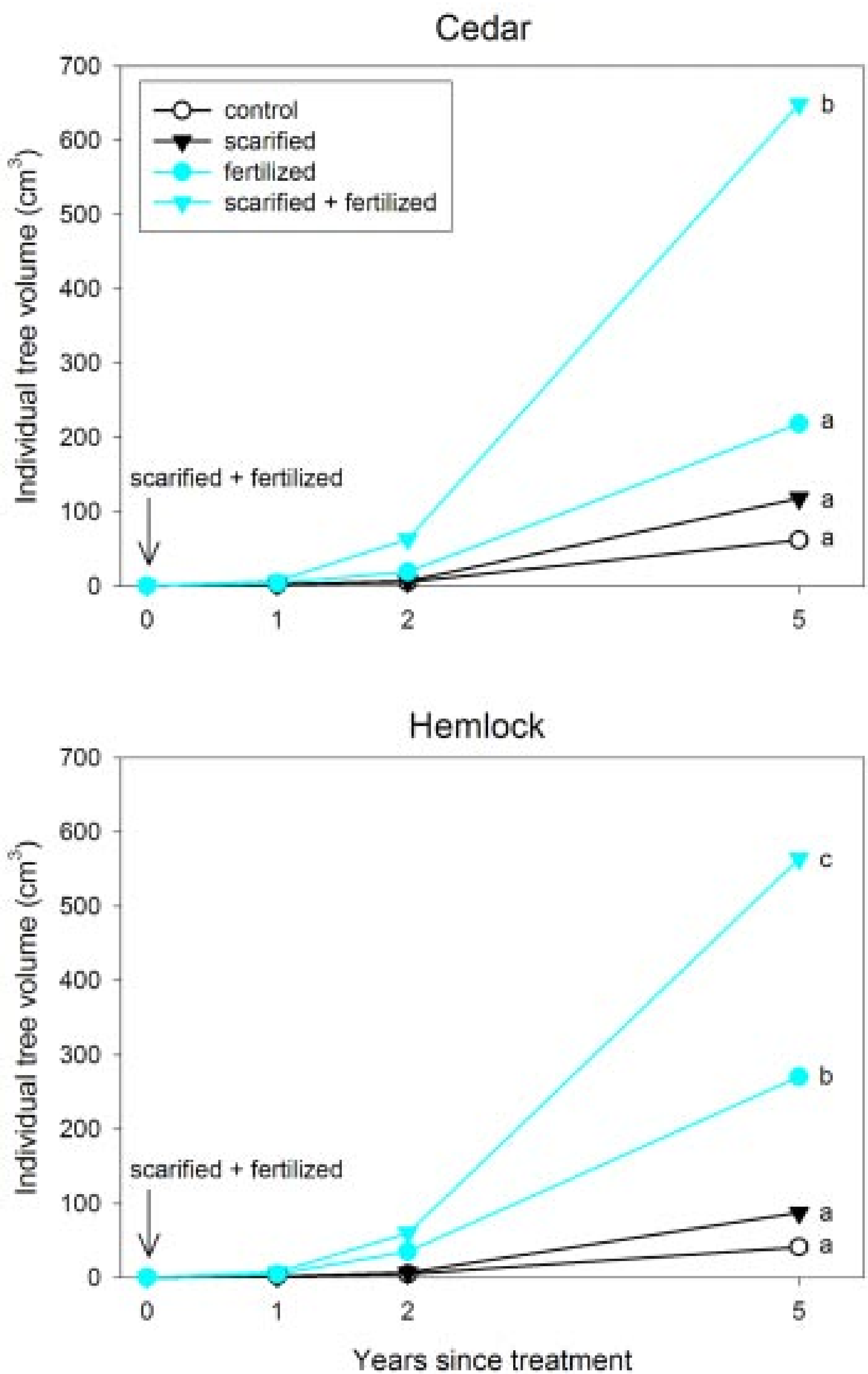

Figure 8. Volume of cedar and hemlock in control, scarified, fertilized and combined (scarified plus fertilized) plots. Different letters indicate differences between five-year volumes (p<0.05).

Table 10. Foliar nutrient concentrations (%) of western hemlock and western redcedar one growing season after establishment, and foliar nutrient concentrations considered adequate for each species (Ballard and Carter, 1986).

	Nutrient concentration (%)		
Western hemlock	N	P	K
Adequate level	1.45	0.35	0.80
Control	0.91	0.18	0.92
Scarification	1.29	0.17	0.96
Fertilization	2.02	0.23	0.78
Scarification + Fertilization	2.29	0.24	0.76
Western redcedar			
Adequate level	1.65	0.16	0.85
Control	0.84	0.13	0.85
Scarification	0.77	0.12	0.89
Fertilization	1.73	0.15	0.73
Scarification + Fertilization	2.06	0.15	0.75

8

Fertilization at planting on CH sites on northern Vancouver Island

Formulations and placement of fertilizer have implications to both the efficacy and the cost of planting programs. These two experiments are a subset of a very comprehensive trial established in Holberg in 1996 to examine these factors. The entire trial consists of 40 various treatment combinations, including 6 controls (no fertilizer treatments). Comparisons of fertilizer to control are not presented here, but as in earlier SCHIRP trials, growth of fertilized seedlings was significantly greater than controls.

Research Trials

Trial One

- **Location:** Holberg
- **Site:** CH
- **Tree species:** planted *Thuja plicata*
- **Year established:** 1996
- **Tree age at establishment:** 0 (stand was established as part of trial)
- **Treatments:**

  All 12 combinations of the following:

1 dose	Briquette 14-3-3 (Vigoro Industries, Woodace®) single dose = 17 g
2 doses	Tab 20-10-5 (J.R. Simplot Company, BEST-TABS®) single dose = 10 g
3 doses	Teabag 25-20-0 (RTI, PLANTER'S PAK, WFP Blend) single dose = 10 g
	Granular 26-25-0 (Coast Agri, WFP Blend) single dose weight = 14 g

- **Number of replicates:** 40
- **Variable measured:** tree height

Granular treatments were 14 g, 28 g, and 56 g (quadruple dose treated as triple dose).

Trial Two

- **Location:** Holberg
- **Site:** CH
- **Tree species:** planted *Thuja plicata*
- **Year established:** 1996
- **Tree age at establishment:** 0 (stand was established as part of trial)
- **Treatments:**

  All 14 combinations of the following:

Tab	0x0	(Depth x Distance to seedling both in cm.; e.g. 0x10 is 0 cm deep, 10 cm from stem)
Teabag	0x10	
	0x20	
	10x0	
	10x10	
	10x20	
	10x5	

- **Number of replicates:** 40
- **Variable measured:** tree height

The trial was established as a randomized complete block design. Forty blocks (rows) contained 40 seedlings, each of which received one of the forty treatment combinations, randomly assigned. A portion of the trial was established on excessively wet ground. Here, mortality was higher than average, so only the top 20 trees of each treatment were included in analyses. There was no evidence of mortality due to fertilizer.

Findings

After five growing seasons, western redcedar heights differed among the formulations and doses of fertilizer treatment (Table 11). Applications of 1, 2, or 3 tabs generally resulted in poorer height growth compared to similar doses in briquettes, teabags, or granular fertilizer. A single dose of any formulation generally resulted in less height growth than did double or triple doses (Plate 13). The interaction effect is significant due to the poor performance of a double dosage of teabags (Table 11, Table 12).

Fertilizer location relative to the seedling also affected height growth. The greatest height response was to fertilizer placed adjacent to the plug (Table 13). Fertilizer placed in the ground more than 5 cm from the plug was no more effective than no fertilizer (Plate 13).

Teabags resulted in greater height growth than did tabs (Table 13). In six of the seven fertilizer locations, seedlings treated with teabags at time of planting were larger, on average, than those with tabs. However, with a surface application adjacent to the plug (0 x 0), there was no significant difference between a single tab and a single teabag. Of the 34 fertilizer applications assessed in this trial, the single teabag at 0 x 0 ranked second in height performance, and the single tab at 0 x 0 ranked fourth in height performance. The present cost of a tab is $0.045 while the cost of a teabag is $0.075.

Conclusions

- Teabags or tabs at a single dose applied to the surface and adjacent to the seedling provide cost-effective fertilizer delivery.
- Fertilization with briquettes, teabags, or granulated fertilizer is recommended to get the best early height growth of western redcedar on CH sites.
- A double dose will provide greater early growth, but triple doses have no additional beneficial effect.
- Fertilizer packets should be placed adjacent to the planted seedling, and may be placed on the surface.
- The choice of fertilizer may not be the same for other conifer species.

Table 11. Average height of the top 20 trees of each treatment five years after fertilization at planting. Fertilizer was placed 10 cm deep and 5 cm from the seedling. Different letters indicate significant differences between formulations (*p*<0.10), based on one-factor ANOVA.

	Average five-year heights (cm)				
Doses	Briquette	Tab	Teabag	Granular	Average
1	124.6	127.5	139.6	129.1	130.2
2	149.4	132.2	129.1	144.7	138.9
3	142.6	128.0	149.4	149.0	142.2
Average	138.9	129.2	139.4	140.9	
**	a	b	a	a	

Table 12. ANOVA table for western redcedar height five years after fertilization at planting with different formulations and doses of fertilizer. Fertilizer was placed 10 cm deep and 5 cm from the seedling. Significant effects (*p*<0.05) are bolded.

Source	*p*-value
Dose	**0.012**
Formulation	**0.064**
Interaction	**0.043**

Table 13. Average height of the top 20 trees of each treatment five years after fertilization at planting. Fertilizer was applied as single doses of tabs or teabags and was placed at seven locations relative to the seedling. Location codes are given as depth x distance to seedling: 0x10 is 0 cm deep, 10 cm. Different letters indicate significant differences between locations relative to seedling (*p*<0.10), based on one-factor ANOVA.

	Average five-year heights (cm)							
Depth x Distance (cm)	0 x 0	0 x 10	0 x 20	10 x 0	10 x 5	10 x 10	10 x 20	Average
Teabag	152.0	132.8	137.6	156.7	139.6	122.2	111.8	136.1
Tab	150.8	126.0	130.0	124.1	127.5	128.6	110.0	128.1
Average	151.4	129.4	133.8	140.4	133.6	125.4	110.9	
**	ab	bc	b	ab	b	c	d	

Table 14. ANOVA table for western redcedar height five years after fertilization at planting with different formulations and fertilizer locations. Fertilizer was applied in a single dose. Significant effects (*p*<0.05) are bolded.

Source	*p*-value
Formulation	**0.008**
Location	**0.000**
Interaction	**0.023**

9

Fertilization at planting on CH sites on western Vancouver Island

The benefits of fertilization at planting on CH sites have been demonstrated in the SCHIRP Installation near Port McNeill. This fertilization at planting trial was established to determine the best fertilizer delivery method for improving the early growth of seedlings.

Research Trial

- **Location:** north of Ucluelet
- **Site:** CH
- **Tree species:** planted *Tsuga heterophylla* and *Thuja plicata*
- **Year established:** 1996
- **Tree age at establishment:** 0 (stand was established as part of trial)
- **Treatments:**

Control (no fertilizer)	
28g granular (26-25-0) surface application	(7.3 g N, 7.0 g P, 0 g K / seedling)
28g granular (26-25-0) 10 cm deep	(7.3 g N, 7.0 g P, 0 g K / seedling)
Silva-Pak teabag 27g (26-12-6) 10 cm deep	(7.0 g N, 3.2 g P, 1.6 g K / seedling)
Apex Gold latex 40g (18-6-12) 10 cm deep	(7.2 g N, 2.4 g P, 4.8 g K / seedling)

- **Number of replicates:** 5
- **Variables measured:** height, basal diameter, seedling condition, foliar nutrient concentrations, vegetative cover

The doses of N delivered by the fertilizers are comparable; however, P and K doses vary considerably among formulations. All fertilizers were placed approximately 10 cm from the seedling except in the surface application, which was placed in a ring around the seedling. For the Silva-Pak teabag, 3 bags were placed in the hole near each seedling in order to provide the dosage listed above.

Findings

After five years, the best growth responses were to either teabags or granular fertilizer applied 10 cm deep (Figure 9). Granular fertilizer applied 10 cm deep was the only fertilizer that significantly increased *both* height and volume of *both* species. Teabags improved both height and volume of western redcedar but not western hemlock. Reasons for the better response of cedar to teabags is not known, but could be related to the different fertilizer formulations (*i.e.*, teabags had less N and P, compared to granular, but had added K).

Granular fertilizer applied on the surface and the fertilizer in latex envelopes (Apex Gold) were the least effective delivery methods; neither method increased volume growth of either species significantly, although both affected height growth. Some volatilization of fertilizer applied to the ground surface likely occurred, decreasing its availability to the trees. Granular fertilizer applied on the surface did not increase western redcedar height growth after five growing seasons, but it had the greatest effect on western hemlock height growth, regardless of delivery method.

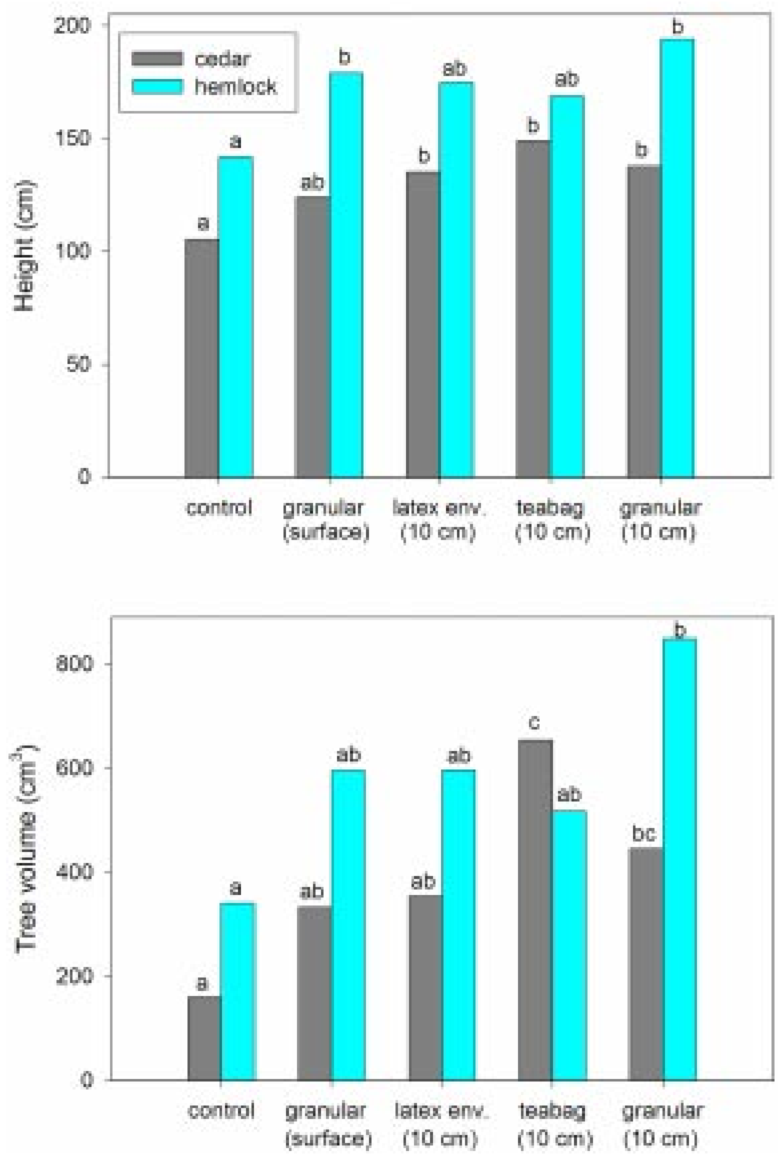

Figure 9. Mean height and individual tree volume at five years for cedar and hemlock fertilized at planting with four delivery methods. Letters above each bar indicate significant differences within each species. Different letters indicate significant differences between treatments ($p<0.05$).

Coated fertilizers with controlled release rates are now more commonly used. Results from these trials indicate that the best delivery method is granular fertilizer inserted 10 cm deep or packaged in a teabag-like mesh bag. Care must be taken in the placement of the fertilizer in relation to the seedling root plug, as some fertilizers can damage new roots when placed in close proximity.

Conclusions

- Granular fertilizer inserted 10 cm into the soil increased volume and height of both cedar and hemlock.
- Teabags improved both height and volume of western redcedar but not western hemlock.
- Granular fertilizer applied on the surface and the fertilizer in latex envelopes were the least effective delivery methods.

10

Fertilization at planting on HA/CH transitional sites

HA/CH transitional sites have overstories that are typical of HA stands but may include a minor component of cedar veterans. The understory contains a minor component of salal, which re-sprouts vigorously after harvest. Hemlock, fir, and spruce regeneration exhibit chlorosis similar to that seen in regenerating CH stands. The efficacy of time-of-planting fertilization on HA/CH transitional sites was tested in this trial.

Research Trial

- **Location:** Port McNeill (3 replicates), Holberg (1 replicate)
- **Site:** HA/CH transitional
- **Tree species:** planted *Tsuga heterophylla* and *Thuja plicata*
- **Year established:** 1996
- **Tree age at establishment:** 0 (stand was established as part of trial)
- **Treatments:** all 18 combinations of the following:

no fertilization (control)	1,000 sph	all western redcedar
fertilization (14 g Custom Blend)	2,000 sph	all western hemlock
	3,000 sph	50-50 Cw and Hw

- **Number of replicates:** 4
- **Variables measured:** tree height and root collar diameter, salal height and root collar diameter, salal cover, salal count, foliar nutrient concentrations

Each of the 18 treatment combinations was included once in each of the four replicates. All planting stock for each species originated from the same seedlot and nursery crop, and was 1 + 0 container stock, 313 PSB. The Custom Blend fertilizer applied was a slow-release fertilizer (26-25-0). A treatment unit consisted of an inner plot of 64 trees surrounded by a minimum of three rows of surrounds. Plot area varied according to planting density.

Establishment heights and root collar diameters were recorded for ten trees of each species selected randomly in each plot. After two and five growing seasons, the height of all 64 trees in each treatment unit was measured. Here we present results for single species plots only.

To quantify the salal competition in each treatment unit, nine subplots of 1 m^2 were established in a systematic grid within the treatment unit. In each subplot, the number of salal stems was counted % cover was estimated. Height and root collar diameters of five dominant salal stems (if available) were measured in the year of establishment and after five growing seasons. Data was first averaged over the subplot, and then over the treatment unit to provide a single value for each treatment unit.

Findings

After five growing seasons, heights of western redcedar and western hemlock were significantly different between fertilized and unfertilized treatments (Table 15). The average fertilized cedar height was 125 cm, while that of unfertilized cedar was 97 cm (Figure 10). This is consistent with findings on HA sites at the SCHIRP installation, where fertilization at planting improved cedar growth. Average fertilized hemlock height was 225 cm after five growing seasons, while unfertilized seedlings were 197 cm. This difference was only marginally significant, and is consistent with the findings of hemlock performance on HA sites in the SCHIRP installation.

After five growing seasons, foliar nutrient concentrations were consistently low, regardless of species or fertilizer treatment (Table 16). In all cases but one, there were no significant differences between fertilizer treatments or densities. Only for P concentration in hemlock was there a significant fertilizer effect (Table 15). Fertilized hemlock had lower P concentrations than unfertilized hemlock (Table 16).

Salal cover and height were not significantly different in fertilized and control plots, or among the various planting densities. Differences are anticipated as the canopy from the conifer regeneration develops.

Conclusions

- On HA/CH transitional sites, western redcedar growth is improved with fertilization at planting.
- On HA/CH transitional sites, western hemlock growth is marginally improved with fertilization at planting.
- On HA/CH transitional sites, western hemlock with or without fertilizer consistently outperforms western redcedar up to age 5.

References

Ballard, T.M. and R.E. Carter. 1986. *Evaluating Forest Stand Nutrient Status*. Land Mange. 20, British Columbia Ministry of Forests, Victoria, 60 pp.

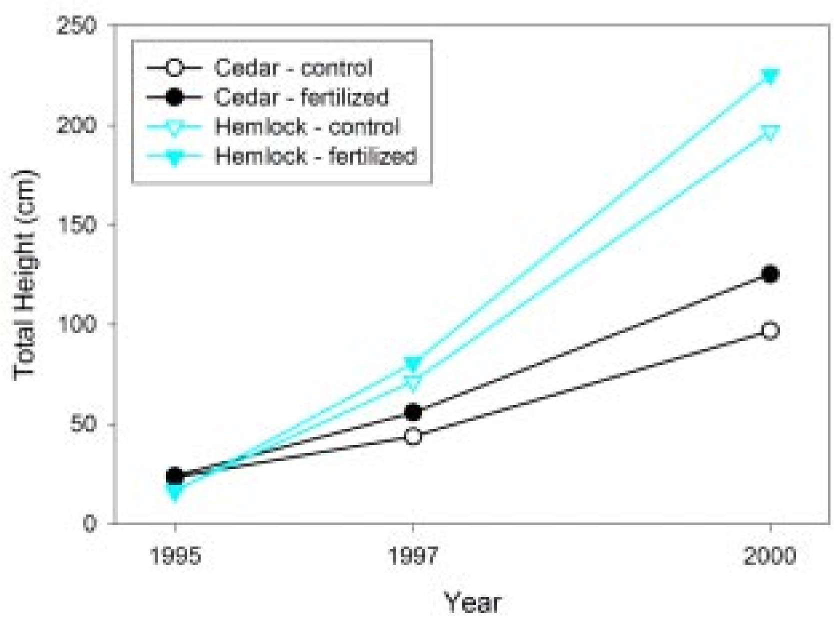

Figure 10. Average height of planted western redcedar and planted western hemlock in single species plots for all densities.

Table 15. ANOVA table for planted western hemlock and western redcedar on HA/CH transitional sites five years after establishment. Significant effects (p<0.10) are bolded.

	p-value			
		Foliar Nutrient Concentration		
	Height	N	P	K
Western hemlock				
Density	0.2078	0.4062	0.5102	0.1625
Fertilization	**0.0992**	0.6235	**0.0372**	0.3414
Interaction	**0.0487**	0.5016	0.7908	0.5387
Western redcedar				
Density	0.7532	0.9931	0.5209	0.3068
Fertilization	**0.0499**	0.2583	0.6261	0.5535
Interaction	0.8892	0.9833	0.9398	0.5829

Table 16. Foliar nutrient concentrations of western hemlock and western redcedar after five growing seasons, together with foliar nutrient concentrations considered adequate for each species (Ballard and Carter 1986).

	Nutrient concentration (%)		
Western hemlock	N	P	K
Adequate level	1.45	0.35	0.80
Control	0.94	0.17	0.71
Fertilized	0.90	0.14	0.73
Western redcedar			
Adequate level	1.65	0.16	0.85
Control	1.34	0.19	0.58
Fertilized	1.27	0.19	0.61

11

Scarification of CH sites and transitional HA/ CH sites

Disruption of salal competition by scarification treatment had a small but measurable effect in the SCHIRP installation (Ch.6). Here we examine the effect of scarification on another CH site (with fertilization) and on a transitional HA/CH site (without fertilization).

Research Trials

Trial One

- **Location:** Port McNeill
- **Site:** CH
- **Tree species:** planted *Thuja plicata* and *Tsuga heterophylla*
- **Year established:** 1996
- **Tree age at establishment:** 0 (stand was established as part of trial)
- **Treatments:** all 4 combinations of the following:

Control (not scarified)	western hemlock
scarified (VH Mulcher)	western redcedar

- **Number of replicates:** 4
- **Variable measured:** tree height

Following scarification, plots were planted at 2000 stems/ha with either redcedar (8 plots) or hemlock (8 plots). All seedlings were fertilized at time of planting with 28 g of custom-blend granular slow-release fertilizer (26-25-0, Coast Agri). After five growing seasons, all trees were measured, and the mean height was compared with single factor analysis of variance.

Trial Two

- **Location:** Port McNeill
- **Site:** HA/CH
- **Tree species:** planted *Thuja plicata* and *Tsuga heterophylla*
- **Year established:** 1996
- **Tree age at establishment:** 0 (stand was established as part of trial)
- **Treatments:** either of the 2 following treatments:
  Control (not scarified)
  Scarified (VH Mulcher)
- **Number of replicates:** 3 scarified, 2 control (all mixed species plots)
- **Variable measured:** tree height

Following scarification, mixed species plots of 64 trees were established at 2000 stems/ha; western hemlock alternating with western redcedar. No seedlings were fertilized. After five growing seasons, all trees were measured, and the mean height of each species within each plot was compared with single factor analysis of variance.

Findings

No significant response to scarification was evident after five growing seasons (Plate 12). Neither western redcedar nor western hemlock show greater height growth on CH or HA/CH transitional ecosystems in response to scarification (Tables 17 and 18).

Conclusions

- Scarification alone does not significantly improve growth in early conifer establishment on CH or HA/CH transitional sites.

Table 18. ANOVA table for western redcedar and western hemlock CH sites and HA/CH transitional sites five years after planting on scarified and control plots.

	p-value
CH Site	
Western redcedar	0.927
Western hemlock	0.293
HA/CH Site	
Western redcedar	0.568
Western hemlock	0.130

Table 17. Average height of trees on CH sites and HA/CH transitional sites five years after planting on scarified and not scarified plots. Seedlings planted on the CH sites were fertilized at planting, and those planted on the HA/CH sites were not fertilized.

	Average Height (cm)	
	Control	Scarified
CH Site		
Western redcedar	144.2	142.8
Western hemlock	204.6	216.7
HA/CH Site		
Western redcedar	123.8	142.8
Western hemlock	267.9	208.5

12

The salal fertilization trial

In other ecosystems, salal has been noted to respond negatively to repeated applications or high rates of N fertilizer. At rates of 400-500 kg N/ha and 1540 kg N/ha salal was almost completely eliminated and conifer volume growth was unaffected or stimulated (Prescott *et al*. 1993). This trial was installed to determine the influence of high N or N + P availability on the reestablishment and growth of salal on clearcut and burned CH sites.

Research Trial

- **Location:** near Port McNeill
- **Site:** CH
- **Tree species:** planted *Tsuga heterophylla* and *Thuja plicata*
- **Year established:**
- **Tree age at establishment:** 2 years
- **Treatments (in kg/ha):** 1998
  - Control (no fertilizers applied)
  - 500N applied in one spring application
  - 500N applied over three years
  - 500N + 200P applied over 3 years
  - 1000N applied in one spring application
  - 1000N applied over 3 years
  - 1000N + 400P applied over 3 years
- **number of replicates:** 4
- **Variables measured:** salal cover and tree heights

Nitrogen was applied as ammonium nitrate (NH_4NO_3) and P as triplesuperphosphate (TSP). Plots receiving 500N over three years were fertilized initially with 300N and then with 50N each spring and fall during the following two years. Plots receiving 1000N over three years were fertilized initially with 600N and then with 100N each spring and fall during the following two years. 200P was applied as 100P the first year and than as 25P during the spring and fall of next two years. 400P was applied as 200P the first year and 50P during the spring and fall of the next two years.

Findings

Salal cover was not significantly affected by any of the fertilization treatments. This lack of significant effect may be due to the highly variable cover of salal on some plots. There very noticeable changes in the cover and composition of the plant species growing on the treatment plots. The plots that received the high inputs of N (1000 kg/ha) alone had a more patchy distribution of salal, which appeared to be less vigorous than on the control plots (Plate 14). On plots fertilized with N+P, salal leaves were a noticeable blue color compared to the salal in control plots or in plots that were fertilized with N alone. Where N and P were applied together, there was also a large increase in the abundance and size of fireweed (*Epilobium angustifolium*) (Plate 14).

The survival and height of the seedlings were significantly reduced by the fertilization treatments. Both cedar and hemlock had lower survival rates on plots fertilized with 1000N (Figure 11). The timing of the application and the addition of P had no significant effect on survival. Hemlock height in plots fertilized with 1000N over two years was significantly lower than in control plots. Cedar height was significantly reduced on plots fertilized with 1000N when it was applied over three years or with P (Figure 12).

Unlike previous investigations with Douglas-fir that demonstrated a positive growth response of conifers to high N additions, the cedar and hemlock seedlings in this study were negatively affected. The fertilizer applications were made much earlier in stand development in this study than in others, so the negative effect may be related to the young age of the trees. Therefore, although high rates of N fertilization will inhibit salal, it should not be applied at the time of planting.

Conclusions

- High doses of N and P appear to promote vigorous growth of fireweed and salal.
- Salal was negatively affected by high doses of N alone.
- Young cedar and hemlock were negatively affected by large applications of fertilizer during their first 5 years.

References

Prescott, C.E., M.A. McDonald, S.P. Gessel and J.P. Kimmins. 1993. Long-term effects of sewage sludge and inorganic fertilizers on nutrient turnover in litter in a coastal Douglas-fir forest. For. Ecol. Manag. **59**: 149-164.

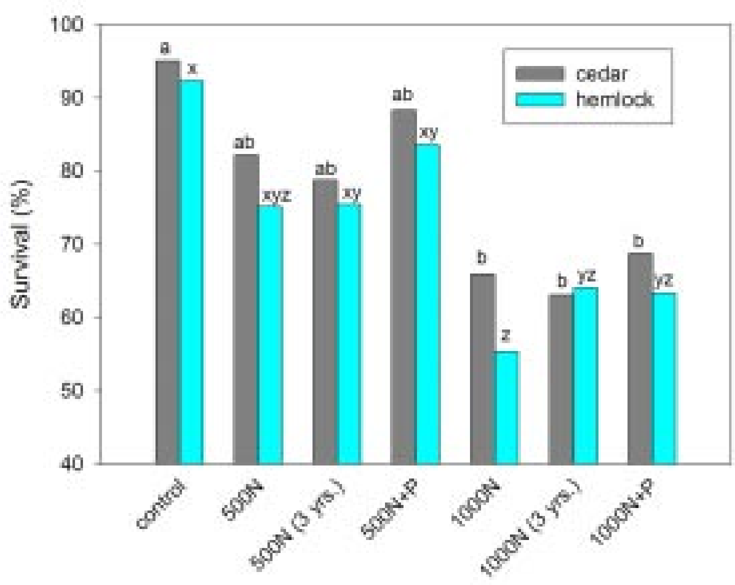

Figure 11. Seedling survival in 2001 (3 years after initial treatment). For each species, different letters indicate significant differences between treatments (p<0.05).

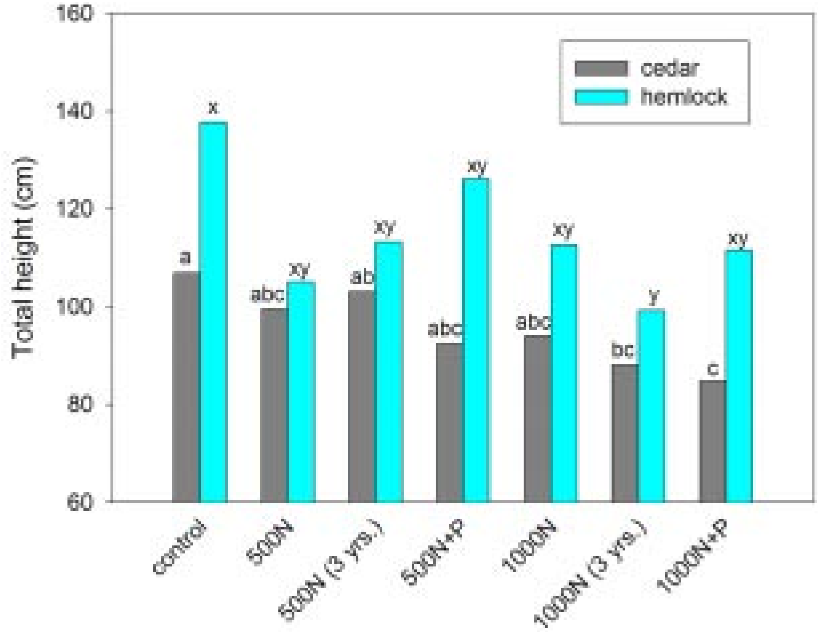

Figure 12. Seedling height (cm) in 2001 (3 years after initial treatment). For each species, different letters indicate significant differences between treatments (*p*<0.05).

13

Financial evaluation of silvicultural options for CH sites

The fertilizer trials established on CH sites indicate that responses are sustained for over a decade. Since the benefits from investments in fertilization will not be realized until final harvest, projection of treated stand performance forms an important part of investment analysis.

In an earlier financial assessment of CH fertilization, Thompson and Weetman (1992) evaluated 4 cases to assess the value of fertilization, given a range of assumptions regarding the expected responses on these sites. One set of assumptions was that volume would not be increased by fertilization, but that a shorter rotation would result. The longer rotation for the unfertilized stands was modeled by simply shifting the yield curve to the right. An alternative approach was to assume that site index was increased by 4 m and that the point at which maximum MAI was achieved was shortened as a result. MAI values increased by 1.9 m^3/ha /yr for cedar and 2.2 m^3/ha /yr for hemlock as a result of these assumptions. They also assumed that a real price increase occurred and modeled several different rates. Their conclusions were as follows:

- Hemlock fertilization is justified financially at rates of return between 3 and 5%.
- Cedar fertilization is only justified if real price increases occur and if responses last more than 5 years, and if cedar stands contain at least 10% hemlock or 25% spruce.
- Fertilization is justified at a discount rate of 3% when the rotation length is reduced by 5 years and, and at a discount rate of 5% when the rotation length is reduced by 10 years.

Since this analysis in 1992, a substantial amount of response data has been collected which indicates that these earlier assumptions were somewhat pessimistic.

Responses

Height measurements have now been made for over a decade in several trials. Using age and height data from the various trials, estimates of site index were determined using Mitchell and Polsson (1988) and are summarized in Table 19. Average values for cedar and hemlock are given in Table 20. When multiple age and height data were available, extrapolated site curves were fitted as illustrated in Figure 13. These figures indicate relative responses by the two species rather than absolute measures of site index.

The average site index values in Table 20 suggest that on the untreated (control) CH sites, the site index for cedar (21 m) is higher than for hemlock (17 m) and that the response to fertilization is greater in hemlock (10 m) than in cedar (4 m). This is consistent with the superior response of hemlock to fertilization found in several SCHIRP trials.

Economic Analysis

To evaluate the economic returns to fertilization, the responses must be projected to rotation age. There is a great deal of uncertainty inherent in this. To deal with this uncertainty, a number of alternative scenarios were evaluated in an attempt to define the responses to a range of management inputs and possible results. These scenarios involved making a number of different assumptions about the nature of the responses.

The assumptions made generally fall into either biological or economic categories. The biological model assumes that, upon crown closure, there will be a shift in soil mineralization processes that will continue throughout the rotation due to the shading out of salal. This requires answers to the following questions.

- How long does a fertilizer response last?

Table 19. Site index estimates for trials on CH sites.

Trial	Fertilization (kg/ha)	Stand age (years)	Site index (m)
Western hemlock			
Plot fertilization (Ch. 2)	N0 P0	17	19
	N300 P100	17	27
Salal removal and fertilization (Ch. 3)	N0 P0	16	17
	N250 P100	18	24
SCHIRP installation (Ch. 6)	N0 P0	10	13
	N225 P75*	10	30
Western redcedar			
Plot fertilization (Ch. 2)	N0 P0	17	26
	N300 P100	17	29
Salal removal and fertilization (Ch. 3)	N0 P0	16	21
	N250 P100	16	23
SCHIRP installation (Ch. 6)	N0 P0	10	15
	N225 P75*	10	24

* fertilizer was applied twice. Values represent the second broadcast fertilization after five growing seasons. There was also a fertilization at planting (10 g N, 2.5 g P, and 5 g K per seedling).

Table 20. Average site indices for control (unfertilized) and fertilized cedar and hemlock trees on CH sites.

Treatment	Average Site Index (m)
Hemlock	
Fertilized	27
Control	17
Cedar	
Fertilized	25
Control	21

- How many fertilizer applications are required to reach crown closure?
- What effect does establishment stocking have on rate of crown closure?
- Will crown closure result in continuing response from more active mineralization activity?

Economic uncertainty is reflected in the costs, prices and discount rates assumed in the analysis. These factors were not investigated in any detail since the objective of this analysis was to portray the anticipated outcomes from fertilization options rather than from different economic assumptions.

Methods

Simulations were carried out using the TIPSY (Version 3.0b) simulator developed by the B.C. Ministry of Forests Research Branch. Costs and prices were assumed to be the default values for the Port McNeill Forest District, although the average haul distance was reduced from 100 to 30 km and the logging system adopted was an overhead cable system. These default values are summarized in Table 21. While these costs are averages as of 1995/

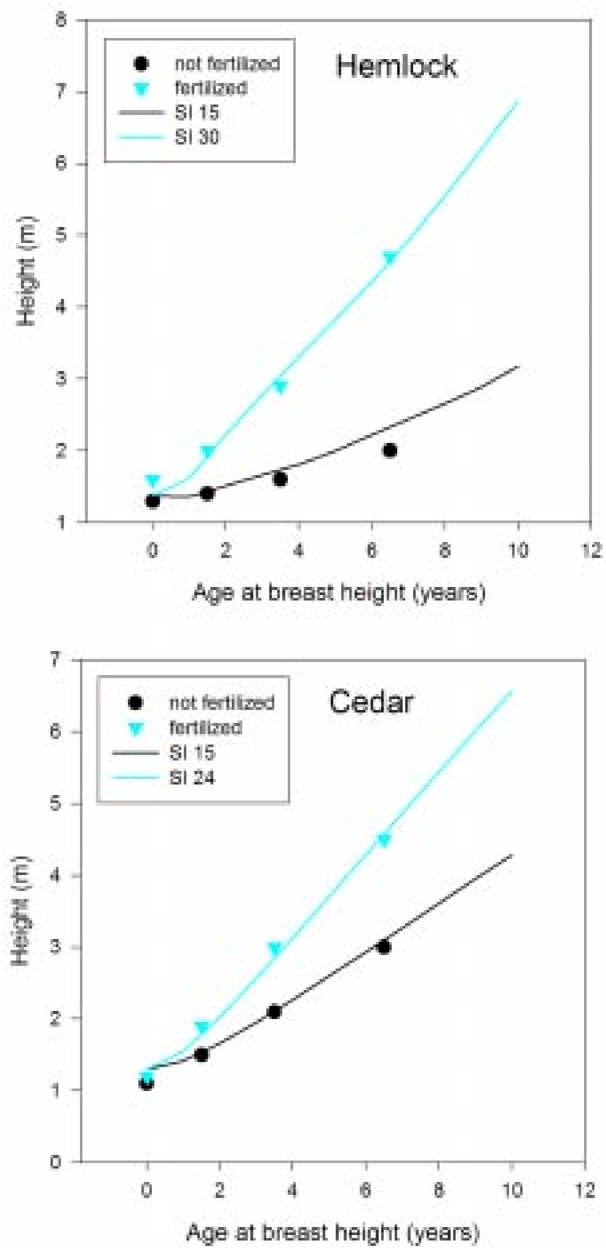

Figure 13. Estimated site indices for cedar and hemlock on CH sites based on height measurements from 1988 to 1997 of the SCHIRP Installation (Ch. 6).

96, relativity between options should be similar to comparisons using more recent values. Inputs reflecting different planting densities, fertilization frequencies and discount rates are shown in Table 22 and Table 23. It was assumed that the real costs and values would not change over time.

On the assumption that crown closure would occur sooner if planting density was higher, planting densities were varied from 500 to 2500 stems/ha. Costs of planting were calculated using the function in TIPSY. Fertilization costs were assumed to be $500/ha at the time of application.

Past observations (Weetman *et al*. 1990) indicate that an assart effect (i.e. increased nutrient availability) will likely be evident for about 5 years after harvesting. Fertilizer applications were therefore assumed to begin 5 years after planting. Based on results reported by Prescott and Weetman (1994), it was also assumed that a period of about 10 years between applications would be required to maintain responses until crown closure occurred. In the analyses, up to 6 fertilizations were possible. Gains were assessed in terms of volumes produced when site index was 27 m at 50 years for pure hemlock stands. An analysis was also done using mixed stands of 40% cedar and 60% hemlock when cedar had a site index of 25 m and hemlock had a site index of 25 m at 50 years (breast height).

The risk associated with uncertain predicted outcomes is often equated with the discount rate assumed. In this case, three rates (3%, 4% and 5%) were assessed. Options were contrasted using soil expectation values (SEVs) achieved at both the optimum economic rotation length (age at maximum SEV) and at the maximum mean annual increment (MMAI) age.

As a baseline comparison, two possible alternatives were evaluated where fertilization was not used. One alternative assumed equivalent planted stand densities as in fertilized stands, but growth rates as if the site index were 17 m. A second alternative comparison was that nothing was done. Natural regeneration, up to the same stocking levels as in planted stands (but clumpy in its distribution) was assumed to occur over a 10 year period. Again, site index was assumed to be 17 m.

Table 21. Default economic data from TIPSY for the Port McNeill Forest District.

Operation	Description	Cost ($)
Harvesting	Tree to truck (function of slope, vol/ha, vol/tree)	*Variable*
	Haul costs	7.80/m^3
	Roads	4000.00
Silviculture	Surveys	19.00/ha
	Planting	*Table 22*
	Fertilization	*Table 23*

Table 22. Model planting costs for different stand densities.

Density (stems/ha)	Planting cost ($)
500	217
1000	377
1500	537
2000	697
2500	856

Results

Planting Density

All results were evaluated at a Discount Rate of 4% (Figure 14). Given the assumption that the gain in site index measured to date can be maintained, several interpretations are possible.

The effect of the various treatment options on stand productivity as indicated by volume, rotation length, and mean annual increment at the age of maximum increment and economic rotation is shown in Table 24. Large increases in final harvest volume result from fertilization and planting. Optimum rotation lengths shift substantially, shortening with fertilization and with choice of an economic rotation. Unless very long rotations are used, an initial stand density of 500 stems/ha results in lower yield than an initial density of 1000 stems/ha.

A comparison of SEV at mean maximum annual increment and optimum economic rotation with various management options is shown in Figure 14. If MMAI rotations are chosen, an optimum planting density of about 1000 stems/ha is indicated if fertilization occurs (see Figure 14, Maximum Mean Annual Increment). At this density, up to 5 fertilizer applications can be expected to give superior results relative to unfertilized options. This is true even if equivalent stocking densities are achieved naturally. Planting and then not fertilizing is a poor economic choice and is outperformed at all stand densities above about 800 stems/ha. At the lowest stand density (500 stems/ha), yields are reduced to the extent that the increased growth from fertilization cannot compensate for the lack of site occupancy. If an optimum economic rotation is chosen, the rotation lengths are shortened and mean annual increment and volume at harvest are also reduced (Table 24). However, the SEV at the lower stand density (500 stems/ha) does not fall off and the optimum financial position is to accept fewer stems per hectare (Figure 14). All fertilization options (1 to 6 applications) are superior to both non-fertilized options up to between 1500 and 2000 stems/ha. Above 2000 stems/ha, up to three fertilizations are still acceptable. These results also predict that establishment densities of between 1000 and 1500 stems/ha are preferable since SEVs do not fall off markedly from the maximum until densities over 1500 are used (Figure 14).

Increased planting density and fertilization is assumed to reduce the time needed to reach crown closure and the initiation of a continued response without additional fertilizer applications. Figure 15 shows the SEV of different combinations of planting density and fertilization that may be required to reduce the time required to reach crown closure. It was assumed that if 2500 stems were planted, two fertilizer applications would suffice to reach crown

Table 23. Discounted cost of fertilizer applications beginning at 5 years and thereafter at 10-year intervals.

	Number of applications					
	1	2	3	4	5	6
Discount rate	Present net value ($/ha)					
3%	431	752	991	1,169	1,301	1,399
4%	411	688	876	1,003	1,088	1,146
5%	392	632	780	870	926	960

closure, whereas if only 500 stems were planted, six fertilizations would be needed. In this example, planting 1000 trees and fertilizing five times is marginally superior to planting 1500 stems and only fertilizing four times. Planting at densities greater than 1500 stems/ha is a poorer investment, despite the need to fertilize fewer times.

Effect of Discount Rate

The effect of an increased discount rate penalized the higher investment options but did not change the trend observed between SEV and increased number of fertilizer applications (Figure 16). At discount rates greater than 4%, the economic benefit of fertilizer application becomes marginal.

Conclusion

The fertilization of CH sites has the potential to greatly increase the yield from these poor sites. At a discount rate below 4 - 4.5% and given reasonable assumptions, multiple fertilizations are economically more appropriate than planting and not fertilizing at stand densities in the range of 1000 to 1500 stems/ha. Non-fertilization options, with or without planting, are not desirable because of the associated slow growth rates and long rotations.

Table 24. Productivity indicators at 500 and 1000 stems/ha with each treatment option (MMAI=maximum mean annual increment, ECON=economic rotation).

Stems/ha	500			1000		
Rotation basis	No planting No fertilizer	Planting No fertilizer	Planting Fertilizer	No planting No fertilizer	Planting No fertilizer	Planting Fertilizer
	Volume (m3/ha)			Volume (m3/ha)		
MMAI	440	882	1483	630	884	1123
ECON	323	472	794	395	523	878
	Rotation length (years)			Rotation length (years)		
MMAI	238	180	125	223	155	88
ECON	186	110	75	155	100	72
	Mean annual increment (m^3/ha/year)			Mean annual increment (m^3/ha/year)		
MMAI	1.8	4.9	11.9	2.8	5.7	12.8
ECON	1.7	4.3	10.6	2.5	5.2	12.2

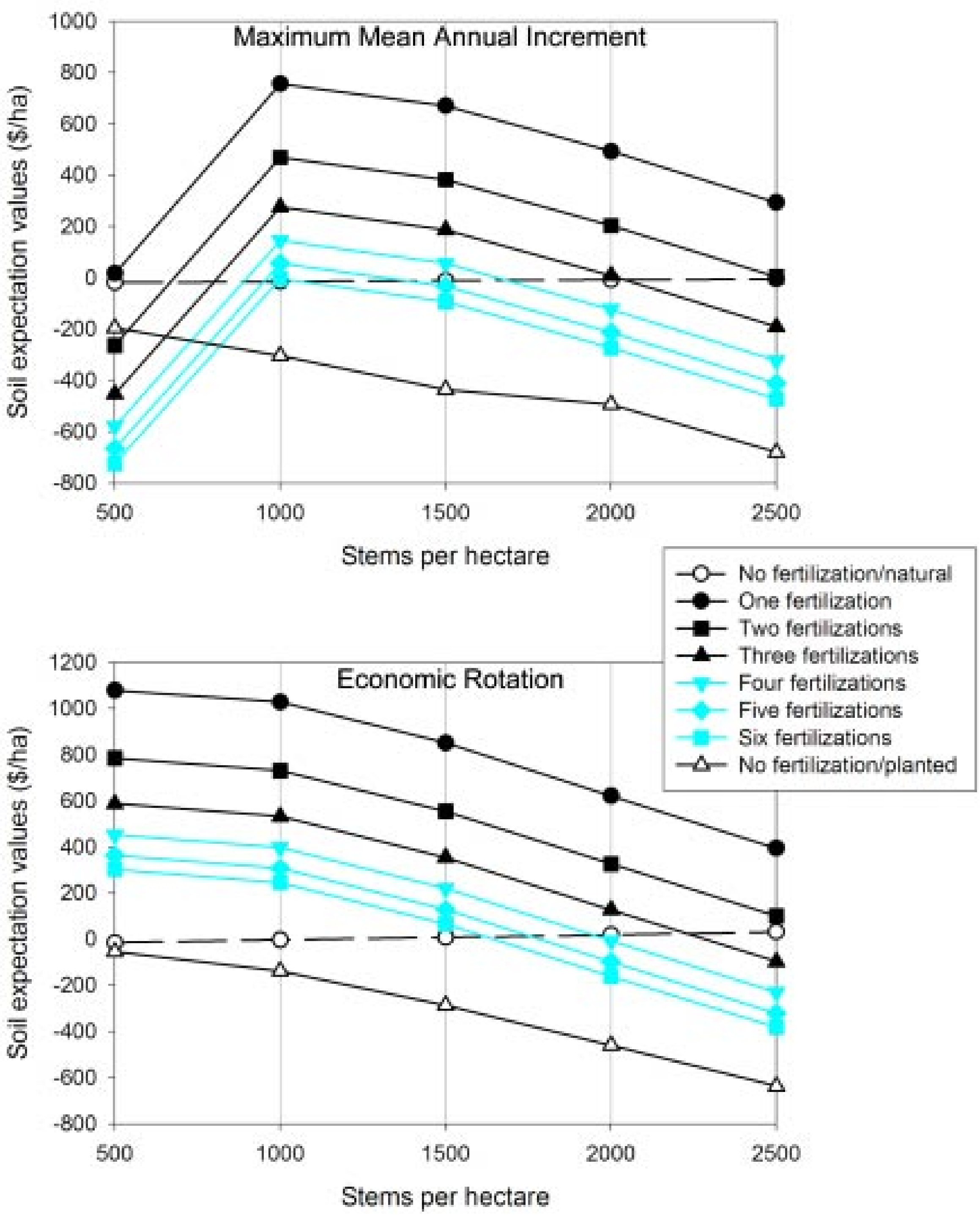

Figure 14. Soil expectation values for hemlock on CH sites (age of maximum mean annual increment) with multiple fertilizations and stocking levels. All values were evaluated at a Discount Rate of 4%.

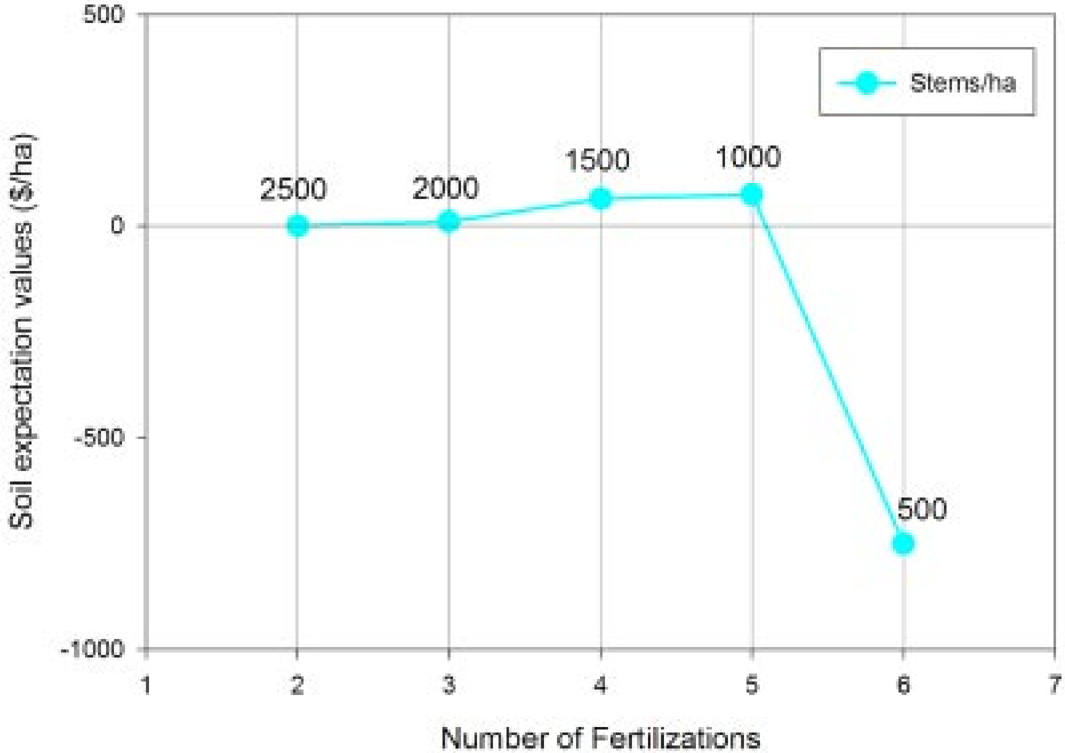

Figure 15. Soil expectation value ($/ha) assuming that different numbers of fertilizer applications are required to achieve crown closure at different planting densities.

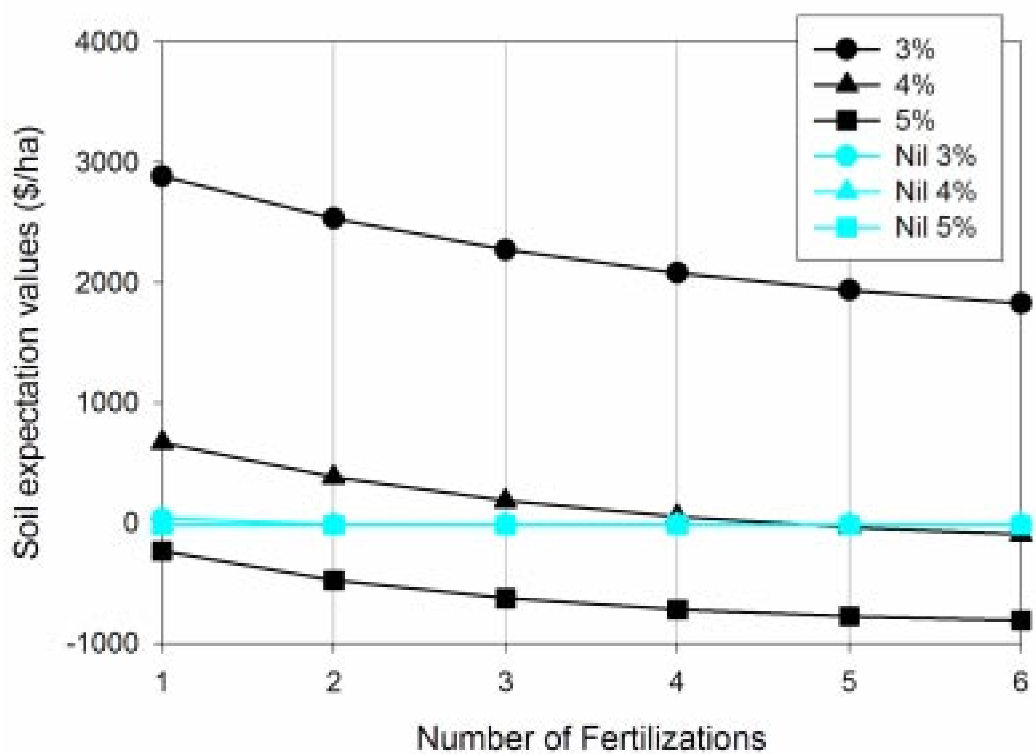

Figure 16. The effect of discount rate on soil expectation value at MMAI rotation and 1500 stems/ha.

References

Mitchell, K. J. and K.R. Polsson. 1988 Site index curves and tables for British Columbia: coastal species. FRDA Report (Victoria, B.C.) No. 037, iii + 29 pp.

Prescott, C.E. and G.F. Weetman. 1994. Salal Cedar Hemlock Integrated Research Program: A Synthesis. Faculty of Forestry, University of British Columbia, Vancouver, B.C. 85 pp.

Thompson, W.A. and G.F. Weetman 1992. Operational fertilization of young stands of cedar, hemlock and spruce on northern Vancouver Island: Five year results and projected economic impact. Report to B.C. Ministry of Forests. 51 pp.

Weetman, G.F., R. Fournier, E. Schnorbus-Pannozzo and J. Barker. 1990. Post-burn nitrogen and phosphorus availability of deep humus soils in coastal British Columbia cedar/hemlock forests and the use of fertilization and salal eradication to restore productivity. *In* S.P. Gessel, D.S. Lacate, G.F. Weetman and R.F. Powers.(eds), Sustained Productivity of Forest Soils. Proc. 7th N. Amer. Forest Soils Conf. pp. 451-499.

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Conclusions and recommendations

- Scarification and vegetation control have little effect on tree growth on previously burned and unburned CH sites, but these treatments increase conifer growth response to fertilization.
- Interplanting with lodgepole pine does not improve the growth of Sitka spruce during the first 10 years, although lodgepole pine growth is superior to other conifers on CH sites.
- Sitka spruce and hemlock are very responsive to fertilization. Cedar is less responsive but produces the most volume on unfertilized CH sites. The greatest responses are with at least 200 kg N/ha and 100 kg P/ha. There is no further response to additional nutrients.
- The greatest response to fertilization is when it is combined with some form of vegetation control (scarification or herbicide).
- Fertilization at planting combined with scarification on CH sites increases the height of cedar at five years from approximately 120 cm on untreated sites to 190 cm on treated sites. Hemlock seedling height is increased from 95 cm to 200 cm after five years. A second fertilization at six years increases cedar volume five times and hemlock volume 50 times after 10 years.
- A single fertilization five to seven years after stand establishment on HA sites doubles the volume of both cedar and hemlock at 10 years.
- Fertilization increases apparent site index from 13 to 30 m for hemlock and from 15 to 24 m for cedar on CH sites. This equals an increase in mean annual increment (MAI) of about 6 to 8 m^3/ha/year.
- At a discount rate below 4 - 4.5% and given reasonable assumptions, planting densities of 1000 to 1500 stems/ha with multiple fertilizations produce the best return on investment when managing CH sites after clearcutting. Non-fertilization options, with or without planting, are not desirable because of the associated slow growth rates and very long rotations.
- If fertilization is not assured, reforestation of CH sites with cedar carries less risk.
- A single application of P fertilizer appears to be sufficient to produce a long-term improvement in conifer P nutrition.
- Urea and ammonium nitrate fertilizers produce similar growth responses in conifers.
- Growth responses to organic fertilizers are similar to responses to chemical fertilizers.
- Granular fertilizer (7.3 g N and 7.0 g P/seedling) placed near the base of the seedling at the time of planting produces the greatest growth response in both cedar and hemlock. Cedar seedlings also respond well to teabags applied at the surface or 10 cm deep.
- Fertilization of CH sites with high rates of N alone inhibits salal but also reduces survival and growth of conifer seedlings.

The results of this suite of silvicultural trials clearly demonstrate that fertilization with N and P is the key to improving the productivity of salal-dominated CH sites. The recommended regime is fertilization at planting, broadcast application of N and P at about 5 years, and supplemental addition of N 5-7 years later. There are signs that enhanced growth will continue once the crowns have closed, but continued monitoring of the trials is necessary to confirm these early indications.

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SCHIRP publications

Prescott, C.E. and G.F. Weetman. 1994. Salal Cedar Hemlock Integrated Research Program: A Synthesis. Faculty of Forestry, University of British Columbia, Vancouver, B.C. 85 pp.

Prescott, C.E. 1996a. Salal Cedar Hemlock Integrated Research Program. Research Update #1: December 1996. Faculty of Forestry, University of British Columbia, Vancouver, B.C. 49 pp.

Prescott, C.E. 1996b. A Field Guide to Regeneration of Salal-Dominated Cedar-Hemlock (CH) Sites in the CWHvm1. Faculty of Forestry, University of British Columbia, Vancouver, B.C. 25 pp.

Graduate theses

Battigelli, J.P. 1992. Soil fauna communities in cedar-hemlock and hemlock-amabilis fir forest types on northern Vancouver Island, British Columbia. M.Sc. Thesis, Dept. of Soil Science, University of British Columbia, Vancouver, B.C. 84 pp.

Bennett, J.N. 2001. The nitrogen nutrition of western redcedar, western hemlock and salal: species-specific mechanisms for accessing nitrogen in cedar-hemlock forests on northern Vancouver Island. Ph.D. Thesis, Dept. of Forest Sciences, University of British Columbia, Vancouver, B.C. 167 pp.

Bothwell, K. 2000. The nitrogen nutrition of lodgepole pine (*Pinus contorta* var. *contorta*) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.) on a cedar-hemlock cutover on northern Vancouver Island. M.Sc. Thesis, Dept. of Forest Sciences, University of British Columbia, Vancouver, B.C. 142 pp.

Cade-Menun, B. 1995. Phosphorus forms in podzols on northern Vancouver Island. Ph.D. Thesis, Dept. of Soil Science, University of British Columbia, Vancouver, B.C. 211 pp.

Chang, S.X. 1996. Fertilizer efficiency and incorporation and soil dynamics in forest ecosystems of northern Vancouver Island. Ph.D. Thesis, Dept. of Forest Sciences, University of British Columbia, Vancouver, B.C. 190 pp.

deMontigny, L. 1992. An investigation into the factors contributing to the growth check of conifer regeneration on northern Vancouver Island. Ph.D. Thesis, Dept. of Forest Sciences, University of British Columbia, Vancouver, B.C. 191 pp.

Fraser, L. 1993. The influence of salal on planted hemlock and cedar saplings on northern Vancouver Island. M.Sc. Thesis, Dept. of Botany, University of British Columbia, Vancouver B.C., 116 pp.

Germain, A.Y. 1985. Fertilization of stagnated Sitka spruce plantations on northern Vancouver Island. M.F. Thesis, Dept. of Forest Sciences, University of British Columbia, Vancouver, B.C. 185 pp.

Husted, L.D. 1982. The relationship between foliar and soil chemistry, growth parameters, and variable height growth in advance regeneration of amabilis fir. M.Sc. Thesis, Dept. of Forest Sciences, University of British Columbia, Vancouver, B.C. 123 pp.

Keenan, R. 1993. Structure and function of western redcedar and western hemlock forests on northern Vancouver Island. Ph.D. Thesis, Dept. of Forest Sciences, University of British Columbia, Vancouver, B.C. 167 pp.

Messier, C. 1991. Factors limiting early conifer growth in salal-dominated cutovers on northern Vancouver Island, British Columbia. Ph.D. Thesis, Dept. of Forest Sciences, University of British Columbia, Vancouver, B.C. 160 pp.

Vales, D. J. 1986. Functional relationships between salal understory and forest overstory. M.Sc. Thesis, Faculty of Forestry, University of British Columbia, Vancouver, B.C. 163 pp.

White, J.B. 2000. Studies of hemlock nutrition. Ph.D. Thesis, Dept. of Forest Sciences, University of British Columbia, Vancouver, B.C.

Xiao, G. 1994. The role of root-associated fungi in the dominance of *Gaultheria shallon*. Ph.D. Thesis. Dept. of Botany, University of British Columbia, Vancouver, B.C. 137 pp.

Journal Publications/Proceedings/Reports

Allen, T.R., F. Nafar, S.M. Berch, and M. Berbee. 1998. Diversity of Ericoid Mycorrhizal Fungi on *Gaultheria shallon*. Inoculum, Newsletter of the Mycological Society of America Conference 49.

Battigelli, J.P., S.M. Berch and V.G. Marshall. 1994. Soil fauna communities in two distinct but adjacent forest types on northern Vancouver Island, British Columbia. Can. J. For. Res. 24: 1557-1566.

Bothwell, K.S., C.E. Prescott, and M.D. Jones. 2001. Factors contributing to the superior growth and N nutrition of 11-year-old lodgepole pine compared to Sitka spruce on a N-poor cedar-hemlock cutover. Can J. For. Res. 31: 1272-1279.

Bouris, K. 1998. Case studies of Adaptive Management. Internal Report, Forest Practices Branch, Ministry of Forests, Victoria, B.C.

Bradley, R.L., B.D. Titus, C.M. Preston, and J.N. Bennett. 2000. Improvement of nutritional site quality 13 years after single application of fertiliser N and P on regenerating cedar-hemlock cutovers on northern Vancouver Island, B.C. Plant and Soil 223: 195-206.

Cade-Menun, B. J. and C.M. Preston. 1996. A comparison of soil extraction procedures for ^{31}P NMR spectroscopy. Soil Sci. 161: 770-785.

Cade-Menun, B.J., and L.M. Lavkulich. 1997. A comparison of methods to determine total, organic and available phosphorus in forest soils. Commun. Soil Sci. Plant Anal. 28: 651-663.

Cade-Menun, B.J., and S. M. Berch. 1997. Response of mycorrhizal western redcedar to organic phosphorus sources and benomyl. Can. J. Bot. 75: 1226-1235.

Cade-Menun, B.J., and S. M. Berch, C. M. Preston, and L.M. Lavkulich. 2000. Phosphorus forms and related soil chemistry of Podzolic soils on northern Vancouver Island I. A comparison of two forest types. Can. J. For. Res. 30: 1714-1725.

Cade-Menun, B.J., and S. M. Berch, C. M. Preston, and L.M. Lavkulich. 2000. Phosphorus forms and related soil chemistry of Podzolic soils on northern Vancouver Island II. The effects of clearcutting and burning. Can. J. For. Res. 30: 1726-1741.

Chang, S.X., C.M. Preston and G.F. Weetman. 1995. Soil microbial biomass and mineralizable N in a clear-cut chronosequence on northern Vancouver Island, British Columbia. Can. J. For. Res. 25: 1595-1607.

Chang, S.X., C.M. Preston, K. McCullough, G.F. Weetman and J. Barker. 1996. Effect of understory competition effect on distribution and recovery of ^{15}N applied to a western redcedar–western hemlock clear-cut site. Can. J. For. Res. 26: 313-321.

Chang, S. X. and C.M. Preston. 1998. Extractability of residual ^{15}N in a coniferous forest soil on Northern Vancouver Island, British Columbia. Soil Biol. Biochem. 30: 1023-1031.

Chang, S. X., C.M. Preston and G.F. Weetman. 1999. Availability of residual ^{15}N in a coniferous forest soil: a bioassay and comparison with chemical extractions. For. Ecol. Manage. 117: 199-209

Chang, S.X. and C.M. Preston. 2000. Understory competition affects tree growth and fate of fertilizer-applied ^{15}N in a Coastal British Columbia plantation forest: 6-year results. Can. J. For. Res. 30: 1379-1388.

Chang, S.X. and L.L. Handley. 2000. Site history affects soil and plant ^{15}N natural abundances ($\delta^{15}N$) in forests of northern Vancouver Island, British Columbia. Ecology 14: 273-280.

deMontigny, L.E., C.M. Preston, P.G. Hatcher, and I. Kogel-Knaber. 1993. I. Comparison of humus horizons from two ecosystem phases on northern Vancouver Island using C-13 CPMAS NMR spectroscopy and CuO oxidation. Can. J. Soil Sci. 73: 9-25.

Fox, C.A., C.M. Preston, C.A. Fyfe. 1994. Micro-morphological and ^{13}C NMR characterization of a Humic, Lignic, and Histic Folisol from British Columbia. Can. J. Soil Sci. 74: 1-15.

Fraser, L., R. Turkington, and C.P. Chanway. 1993. The biology of Canadian weeds. 102. *Gaultheria shallon* Pursh. Can. J. Plant Sci. 73: 1233-1247.

Fraser, L.H., C.P. Chanway and R. Turkington. 1995. The competitive role of *Gaultheria shallon* on planted western hemlock and western redcedar saplings on northern Vancouver Island. For. Ecol. Manage. 75: 27-39.

Keenan, R.J., C.E. Prescott and J.P. Kimmins. 1993. Mass and nutrient content of the forest floor and woody debris in western redcedar and western hemlock forests on northern Vancouver Island. Can. J. For. Res. 23: 1052-1059.

Keenan, R.J., C. Messier and J.P. Kimmins. 1994. Effects of clearcutting and soil mixing on soil properties and understory biomass in western redcedar and western hemlock forests on northern Vancouver Island, Canada. For. Ecol. Manage. 68: 251-261.

Keenan, R.J, J.P. Kimmins and J. Pastor. 1995a. Modelling carbon and nitrogen dynamics in western redcedar and western hemlock forests. *In* J.M. Kelly and W.W. McFee (eds.), Carbon Forms and Functions in Forest Soils. Soil Sci. Soc. Amer., Madison, WI.

Keenan, R.J., C.E. Prescott and J.P. Kimmins. 1995b. Litter production and nutrient resorption in western redcedar and western hemlock forests on northern Vancouver Island. Can. J. For. Res. 25: 1850-1857.

Keenan, R.J., C.E. Prescott, J.P. Kimmins, J. Pastor, and B. Dewey. 1996. Litter decomposition in western redcedar and western hemlock forests in northern Vancouver Island, British Columbia. Can. J. Bot. 74: 1626-1634.

Mallik, A. and C.E. Prescott. 2001. Growth inhibitory effects of salal on western hemlock and western redcedar: allelopathy and competition. Agron. J. 93: 85-92.

McDonald, M.A., B.J. Hawkins, C.E. Prescott, and J.P. Kimmins. 1994. Growth and foliar nutrition of western redcedar fertilized with sewage sludge, pulp sludge, fish silage and wood ash on northern Vancouver Island. Can. J. For. Res. 24: 297-301.

Messier, C., T.W. Honer and J.P. Kimmins. 1989. Photosynthetic photon flux density, red:far-red ratio, and minimum light requirement for survival of *Gaultheria shallon* in western redcedar–western hemlock stands in coastal British Columbia. Can. J. For. Res. 19: 1470-1477.

Messier, C. and J.P. Kimmins. 1990. Nutritional stress in *Picea sitchensis* plantations in coastal British Columbia: the effects of *Gaultheria shallon* and declining site fertility. Water, Air, Soil Pollut. 54: 257-267.

Messier, C. and J.P. Kimmins. 1991. Above- and belowground vegetation recovery in recently clearcut and burned sites dominated by *Gaultheria shallon* in coastal British Columbia. For. Ecol. Managem. 46: 275-294.

Messier, C. 1992. Effects of neutral shade and growing media on growth, biomass allocation, and competitive ability of *Gaultheria shallon*. Can J. Bot. 70: 2271-2276.

Messier, C. 1993. Factors limiting early growth of western redcedar, western hemlock and Sitka spruce seedlings on ericaceous-dominated clearcut sites in coastal British Columbia. For. Ecol. Manage. 60: 181-206.

Messier, C., R. Keenan and J.P. Kimmins. 1995. The effects of soils mixing on soil nutrient status, recovery of competing vegetation and conifer growth on cedar-hemlock cutovers in coastal British Columbia. New Forests 9: 163-179.

Monreal, M., S.M. Berch and M.L. Berbee. 1999. Molecular diversity of ericoid mycorrhizal fungi. Can. J. Bot. 77: 1580-1594.

Prescott, C.E., M.A. McDonald and G.F. Weetman. 1993. Availability of N and P in the forest floors of adjacent stands of western redcedar-western hemlock and western hemlock - amabilis fir on northern Vancouver Island. Can. J. For. Res. 23: 605-610.

Prescott, C.E. and M.A. McDonald. 1994. Effects of starch and lime additions on mineralization of C and N in humus from western redcedar - western hemlock forests on northern Vancouver Island. Can. J. For. Res. 24: 2432-2438.

Prescott, C.E. and C.M. Preston. 1994. Nitrogen mineralization and decomposition in adjacent plantations of western redcedar, western hemlock and Douglas-fir. Can. J. For. Res. 24: 2424-2431.

Prescott, C.E., L.E. deMontigny, C.M. Preston, R.J. Keenan, and G.F. Weetman. 1995. Carbon chemistry and nutrient supply in cedar-hemlock and hemlock-amabilis fir forest floors. pp. 377-396 *In* J.M. Kelly and W.W. McFee (eds.), Carbon Forms and Functions in Forest Soils. Soil Sci. Soc. Amer., Madison, WI.

Prescott, C.E., G.F. Weetman, and J.E. Barker,.1996. Causes and amelioration of nutrient deficiencies in cutovers of cedar-hemlock forests in coastal British Columbia. For. Chron. 72: 293-302.

Prescott, C.E. and L.M. Zabek. 1997. Growth response and nutrient availability in western redcedar plantations following amendment with fish-wood compost and straw. Can. J. For. Res. 27: 598-602.

Prescott, C.E. and S.M. Brown. 1998. Five-year growth response of western redcedar, western hemlock, and amabilis fir to chemical and organic fertilizers. Can. J. For. Res. 28: 1328-1334.

Prescott, C.E. and L.L. Blevins. 1999. The Salal Cedar Hemlock Integrated Research Program (SCHIRP): management through understanding. For. Chron. 75: 447-451.

Preston, C. M., 1999. Condensed tannins of salal (*Gaultheria shallon* Pursh): a contributing factor to seedling “growth-check” on northern Vancouver Island? *In* Plant Polyphenols: Chemistry and Biology, G. G. Gross, R. W. Hemingway and T. Yoshida (Eds.), Proceedings of the Third Tannin Conference, July 20-25, 1998, Bend, Oregon. Plenum Publishing Co., New York.

Weetman, G.F., R. Fournier, J. Barker, E. Schnorbus-Panozzo, and A. Germain. 1989a. Foliar analysis and response of fertilized chlorotic Sitka spruce plantations on salal-dominated cedar-hemlock cutovers on Vancouver Island. Can. J. For. Res. 19: 1501-1511.

Weetman, G.F., R. Fournier, J. Barker, and E. Schnorbus-Panozzo. 1989b. Foliar analysis and response of fertilized chlorotic western hemlock and western redcedar reproduction on salal-dominated cutovers on Vancouver Island. Can. J. For. Res. 19: 1512-1520.

Weetman, G.F., R. Fournier, E. Schnorbus-Panozzo, and J. Barker. 1990. Post-burn nitrogen and phosphorus availability of deep humus soils in coastal British Columbia cedar/hemlock forests and the use of fertilization and salal eradication to restore productivity. pp. 451-499 *In* S.P. Gessel, D.S. Lacate, G.F. Weetman and R.F. Powers (eds), Sustained Productivity of Forest Soils. Proc. 7th N. Amer. Forest Soils Conf., Faculty of Forestry, University of British Columbia, Vancouver, B.C.

Weetman, G.F., M.A. McDonald, C.E. Prescott, and J.P. Kimmins. 1993. Responses of western hemlock, Pacific silver fir, and western redcedar plantations on northern Vancouver Island to applications of sewage sludge and inorganic fertilizer. Can. J. For. Res. 23: 1815-1820.

Weetman, G.F. and C.E. Prescott. 2000. The structure, functioning and management of old-growth cedar-hemlock-fir forests on Vancouver Island, British Columbia. pp. 275-287 *In* Julian Evans (ed.)The Forest Handbook Volume 2.

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Plates

Plate 1. Old-growth CH (cedar-hemlock) forest (photo by David Blevins).

Plate 2. HA (hemlock-amabilis fir) forest.

Plate 3. Chlorotic, slow-growing amabilis fir on a CH site surrounded by salal (photo by Candis Staley).

Plate 4. Pine as a nurse species trial: Sitka spruce interplanted with lodgepole pine All trees are 12 years old (photo by Karen Bothwell).

Plate 5. Pine as a nurse species trial: Sitka spruce planted alone. Planted pines can be seen in the background. All trees are 12 years old (photo by Cindy Prescott).

control
(unfertilized)
amabilis fir

fertilized
amabilis fir

Plate 6. Organic fertilization trial: treatments shown are control (unfertilized) amabilis fir and amabilis fir fertilized with 225 kg/ha N and 75 kg/ha P. Trees are 21 years old (photos by Nora Berg and Candis Staley).

scarified only
(unfertilized)

fertilized only (unscarified)

fertilized and scarified

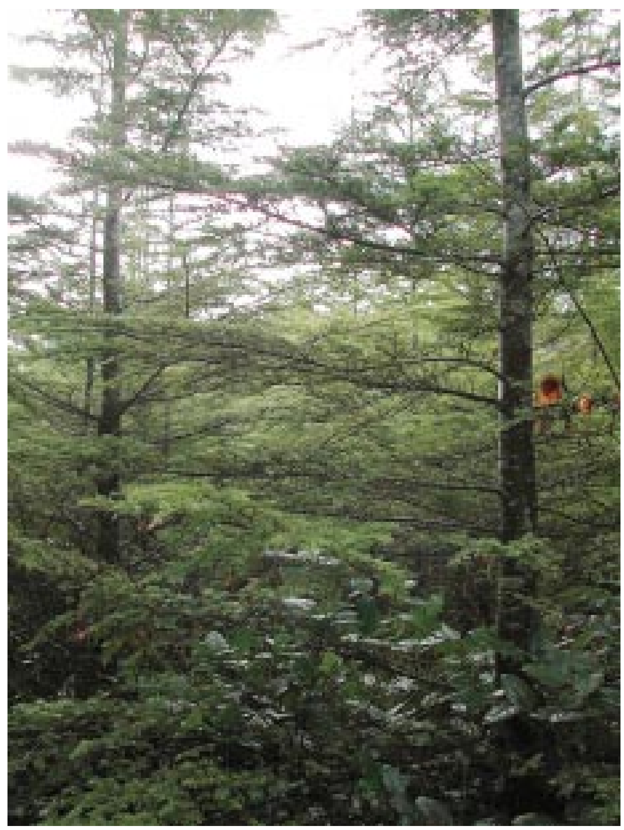


Plate 7. The SCHIRP Installation: 14-year-old western hemlock growing on a CH site. The treatments shown are scarification prior to stand establishment, fertilization at planting and at six years, and scarification and fertilization combined (photos by Nora Berg and Candis Staley).

Plate 8. The SCHIRP Installation: western redcedar growing on a scarified only (unfertilized) CH site. Trees are 14 years old (photo by Nora Berg).

Plate 9. The Kennedy Lake trial: 5-year-old western hemlock and western redcedar growing on a control (not scarified or fertilized) CH site. Note the large amount of deer fern (Jeff Sandford).

Plate 10. The Kennedy Lake trial: 5-year-old western hemlock and western redcedar growing on a fertilized only (not scarified) CH site (photo by Jeff Sandford).

Plate 11. The Kennedy Lake trial: 5-year-old western hemlock growing on a fertilized and scarified CH site (photo by Jeff Sandford).

Plate 12. The scarification trial: western hemlock growing on an unscarified, fertilized CH site (photo by Marie Robertson)..

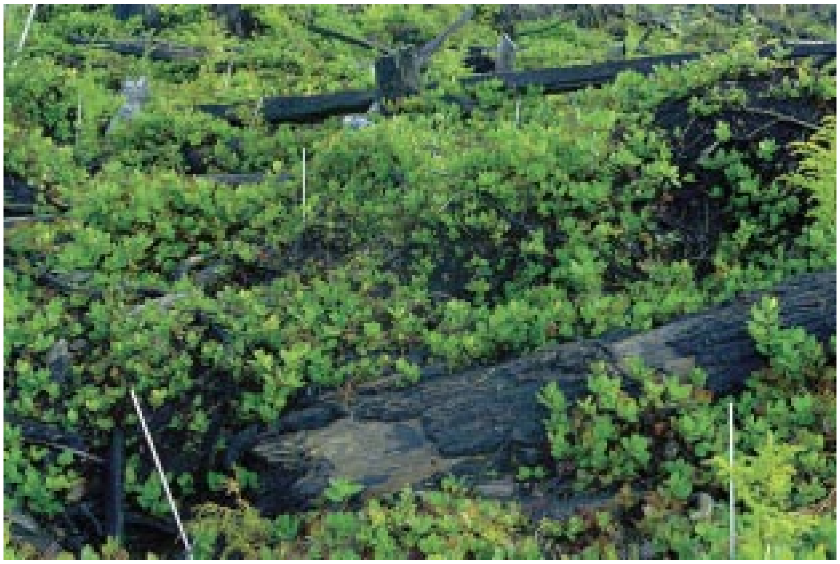
3 teabags 10 cm deep, 5 cm from the seedling

1 tab on the surface, 20 cm from the seedling

28g granular on the surfaced, within 30 cm radius of the seedling

1 teabag 10 cm deep, 10 cm from the seedling

Plate 13. The fertilization at planting trial, northern Vancouver Island (western redcedar): several different fertilization at planting techniques are shown (photos by Annette Van Niejenhuis)



Control

1000 kg/ha N

1000 kg/ha N +
400 kg/ha P

Plate 14. CH plots three years after establishment of the salal fertilization study. Treatments shown are control plots, one application of 1000N, and 1000N + 400P applied over three years. Trees are 5-year-old cedars and hemlocks (photos by Cindy Prescott).