Montane Alternative Silvicultural Systems (MASS) Project

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Growth check in amabilis fir at the MASS study site

by

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INTRODUCTION

A prolonged slowdown in the growth of conifer regeneration known as 'growth check' is a problem often encountered on coastal montane (700-1100m) clearcuts. It is characterized by reduced height increment and chlorotic foliage and does not usually affect regeneration until approximately five to eight years after harvesting, coincident with the expansion of ericaceous shrubs and termination of any post-harvest nutrient flush from an assart effect (Husted 1982, Prescott et al. 1996, Bradley et al. 2002). These growth problems are hypothesized to be caused by limited nutrient availability, vegetation competition and alterations to ecosystem processes affecting forest regeneration. Potential risks for the forest industry include delays in free-to-grow status, significantly longer rotations, reduced site quality and in severe cases long-term site degradation to shrub-dominated ecosystems that are unproductive and unlikely to produce marketable timber (Damman 1971, Weetman et al.1989, Newton P.F. 1998, Bradley et al. 2000). Growth check is often associated with vigorous ericaceous shrub competition on nutrient-poor sites in low elevation coastal cedar-hemlock-salal forests (Prescott et al.1996) in B.C. and black spruce-Kalmia forests in eastern Canada (Damman 1971, Mallik 2003) where the problem has received considerable study. In these forest types ericaceous shrubs immobilize nutrients in biomass and can inhibit tree growth through a combination of competition for soil nutrients, primarily N and P (Chang et al 1996), and allelopathic mediated effects resulting in recalcitrant organic soils that degrade site quality (Mallik 2003).

In higher elevation western hemlock-amabilis fir-western redcedar forests where regeneration is constrained by cold soils and a shorter growing season, little is known about the underlying causes of growth check and the potential for silvicultural mitigation using alternative silvicultural systems and vegetation control (Koppenaal and Mitchell 1992). On many of these montane sites *Vaccinium* species and fireweed are the dominant competitors following harvesting (B.Titus pers. comm.) and are major sinks for N (Kimmins et al 2002, Mitchell et al 2007), considered a growth limiting nutrient in coastal B.C. forests. *Vaccinium* species are ericaceous shrubs that have been implicated in conifer growth check in eastern Canada (Thiffault et al 2005) and parts of Europe (Jaderlind et al. 1997). There is some evidence that these shrubs also adversely affect conifer growth on high elevation cutovers in coastal B.C. (Hawkins and Moran 2003, B. Titus pers. comm.).

At MASS, 15 years after inception, there are indications that much of the conifer regeneration has gone into check providing a unique opportunity to evaluate the growth response of planted regeneration during this critical period by comparing performance in three alternative systems with and without vegetation control. In this study we intensively sampled a subset of the planted amabilis fir from three of the silvicultural systems (clearcut, green tree retention and patch-cut) and two of the post-planting treatments (untreated and herbicide) implemented in the MASS study with the objective of determining the onset and progression of growth check and likely contributing factors. The determinant growth of amabilis fir allowed the onset and progression of growth check to be readily determined from annual height increments from previous years. Silvicultural systems and vegetation control treatments (included as split plots in all silvicultural systems) were evaluated for their effectiveness in mitigating the effects of growth check. To assess the influence of competing vegetation and nutrient status on conifer growth, the cover and proximity of ericaceous shrubs, conifer stem competition (density), and foliar nutrient concentrations were determined on single tree sample plots.

METHODS

Study Site

The MASS project is a long term forest research installation located on private land (Island Timberlands Ltd) south of Campbell River on Vancouver Island (latitude 49 º50' N; longitude 125 º 25'E). Research and maintenance is conducted through agreements with Western Forest Products and the Canadian Forest Service. MASS was initiated in 1993 and includes replicated treatments representing a range of overstory removal (shelterwood, patch cut, and green tree retention) and adjacent old growth and clearcut control areas. The silvicultural treatments are described in detail by Arnott and Beese (1997). The study was designed as a split-plot experiment with each of the silvicultural treatments assigned three replicate nine ha blocks. Within each of these blocks 12 permanent sample plots (PSP's) were randomly assigned from grid points of a 30X 30 meter grid within a core area buffered by at least two tree lengths. These were further divided into four quadrants (split-plots) each planted with three amabilis fir and three western hemlock. Each quadrant received a different post-planting treatment (fertilized, herbicide and fertilizer, herbicide and an untreated control). Details of the planting stock and post planting treatments are given by Dunsworth and Arnott (1995).

Experimental Design

In conjunction with the15 year re-measurment a subset of amabilis fir were selected from the MASS experimental design for intensive measurement and microsite characterization in order to determine the level of "growth check" and identify contributing factors. Western hemlock was not included due to the difficulty in determining annual height increments from the stem. The shelterwood system was excluded from the study since the comparatively high level of overstory shading is the primary growth limiting factor in this system. Trees on split-plots treated with herbicide (Vision applied from 1994-1997) were compared to untreated trees in the three silvicultural systems studied. This post-planting treatment was included in the study based on earlier MASS assessments that indicated that herbicide produced the best growth response of the post-planting treatments tested (Mitchell et al. 2007). Eight to ten permanent sample plot (PSP) locations (replicates) were selected from three blocks of the clearcut and patch-cut systems and from two blocks in the green tree and were randomly chosen except that PSP locations with high mortality were avoided. This may have had the effect of underestimating growth check since at least some of the plots with high mortality may have been on microsites where growing conditions were poor. Height increments, foliar nutrient concentrations, vegetation cover and regeneration density was assessed on single-tree plots ($7m^2$) that were centered around every live planted amabilis fir in untreated and herbicide split-plots of the selected PSP's. Depending on mortality two to three single tree plots were sampled in each split-plot (veg. control and untreated) at a PSP location. Between 25 to 29 single tree plots were sampled for each silvicultural system and vegetation control treatment combination. Sampling was conducted in September 2009.

Height increment
Annual increments from year 8 (2001) to year 15 (2008) were measured for each tree using height poles. Data from previous assessments was used to provide increment information prior to 2001. Caliper data is available from the15 year overall assessment.

Competition
Competition was measured within a plot radius of 1.493 meters from the stem for a total area of 7 m^2 around each measured tree (for practical purposes 1.5 meters was used in the field). Understory ground cover within the plot was categorized as Vaccinium spp., fireweed and others shrubs. Where the other shrubs made up a significant percentage (>1%) the species was noted. Cover classes were based on section G in Habitat Monitoring Committee (1996) where 0 = 0%, 1 = < 5%, 2 = 5-25%, 3 = 25-50%, 4 = 50-75% and 5 = >75% for each category. For the purposes of graphical display the 0% and <5% classes were combined. In addition, the distance from the stem of the measured tree to the nearest Vaccinium foliage was recorded.

Conifers within 1.5 meters of the measured tree and over 0.5 meters in height were counted to determine regeneration density and categorized as either more or less than one and a half times the sample tree height (trees in the former category were likely to have significant impacts on light).

Nutrient Analysis
Current year foliage was sampled for nitrogen and phosphorus. Samples were dried for a minimum of 48 hours at 70 º then ground using a modified coffee grinder. The samples were analyzed at the Canadian Forest Service Northern Forestry Centre in March 2009. Foliar nitrogen was analyzed as total % nitrogen using a Kjeldhal digestion method. Total foliar phosphorus used microwave digestion (EPA Method 3051) followed by analysis using inductively coupled plasma optical emission (ICP-OES). Due to a backlog of samples the number of foliage samples that could be analyzed by March 31 2009 was limited. Samples were therefore selected from each of the silvicultural treatments and two post-planting treatments to represent trees that were showing consistent good growth and trees showing reduced increment growth or “growth check”.

Microsite
Microsite information and the condition for each tree were noted. Shade was recorded as open/full sun (at least 75% of incoming), partial shade (25-75% of incoming) or shaded (less that 25% of incoming) and overstory trees within 3 meters were noted.
Location was recorded as flat/level, knoll or ridge top, slope (greater then 30 degrees) or depression and aspect. Moisture class was based on Green and Klinka (1994) for the CWHmm2 site classification and noted as dry, mesic or seepage.

Statistical analysis
Foliar nutrient data from individual trees were subjected to analysis of variance and means were compared according to Tukey’s test (SAS Institute 1992). Coefficients of determination (r^2) between height measure and foliar nutrients were calculated (SAS Institute 1992) using each tree as an individual observation. Since the corresponding MASS 15-year assessment showed no significant differences in tree height between the clearcut, green tree and patch-cut silvicultural

systems height data from these systems was analyzed in combination as well as separately. Height data in the accompanying line and bar graphs represent means (of PSP replicates) ± one standard error.

RESULTS

Microsite

Sample tree plots were predominately mesic (site series 1, 3-8) as determined by plant associations for the CWHmm2 (Green and Klinka 1994) with only 9 plots on dry sites (site series 2) and 5 plots on seepage sites (site series 9 and 10). Topography was generally flat to moderately sloping with a few plots on knolls and depressions, some of which were associated with dry and seepage sites respectively. Site aspect was generally north or northwest.

Height growth

Recent annual height increment (mean of the last 3 years) in untreated amabilis fir was strongly correlated (R^2= 0.80, $p<0.0001$) with 15 year total height for the combined CC, GT, PC silvicultural systems, confirming it as a reliable indicator of tree performance. Annual height increment growth of amabilis fir peaked 9 to 10 years (2002 – 2003) after planting and declined sharply in the following two years, marking the onset of growth check, and generally remained at depressed annual increments to the present (2008) (Fig. 1). Although this general pattern was observed in the three silvicultural systems examined (CC, GT, PC), mean annual increment was without exception highest in the trees on plots that had been treated with herbicide in the first 4 years after planting (Fig. 2). Although height increments were higher in trees which had been treated with herbicide than in those without (untreated) they still displayed a similar pattern of reduced annual increment growth beginning 10 to 11 years after planting and remaining flat (no increase in increment growth) in the last 4 years (Fig 3.). Silvicultural systems had a smaller effect on increment growth than vegetation control, although following the onset of growth check in year 11 trees in the CC tended to have greater height increments than their counterparts in the GT and PC (Fig. 2). Trees in the CC plots treated with herbicide showed the least year to year fluctuation with year 15 increments not much lower that at their peak in year 10. Compared to the CC and GT, trees in the PC had a steeper and continuing rate of decline in annual increment from their peak levels in 2002.

When divided into height increment classes representing the average annual increment of the last 3 years, overall (CC, GT and PC combined) 45% of the untreated trees were in the lowest increment class (<10 cm) compared to 17% of the trees treated with herbicide (Fig. 4). Prolonged annual increments of 10 cm or less can be considered symptomatic of growth check. Conversely only 26% of the untreated trees had annual increments over 25 cm compared to 58% of the trees in plots that had received herbicide. While silvicultural systems had a smaller effect on increment growth than herbicide treatment, the CC had the highest proportion of trees with annual increments over 40 cm and the lowest proportion of trees with annual increments less than or equal to 10 cm in trees with and without vegetation control respectively (Fig. 5). In contrast to the CC, untreated plots in the PC had proportionately the most trees with annual increments of 10cm or less and the fewest with increments over 25 cm, while in plots treated with herbicide the GT had the most trees with increments under 10 cm and the fewest with increments over 25 cm.

The large effect of vegetation control (herbicide) on height growth is reflected in height distribution since planting and reveals a growing differential and clustering over time between smaller and larger trees particularly in those without herbicide treatment (Fig. 6). Height classes of 15 year old planted amabilis fir are shown in Figures 7 and 8. Overall (Fig.6: CC, GT, PC combined) more than half of the untreated trees were under 2.5 m in height and only 10% were over 5 m which may result in delayed canopy closure and rotation time probably not meet / fall well short of growth and yield expectations for this site. In contrast only 9% of trees treated with herbicide were under 2.5 m in height and 42% of trees were over 5m after 15 years resulting in a height distribution with a greater potential for crown closure and a shorter rotation time.

Foliar Nitrogen and Phosphorus

Nitrogen concentrations in current-year foliage of planted amabilis fir were at deficient levels (untreated: 0.48% – 0.97 %; herbicide: 0.43% - 0.87%) and contrary to expectations were on average higher in trees in plots without herbicide treatment, although the difference between trees with and without vegetation control was only significant in the CC (Table 1). Lower N concentrations in trees treated with herbicide, which were generally larger than untreated trees, may have been due to dilution in biomass. There were no significant ($P \leq 0.05$) differences in foliar N among the three silvicultural systems (Table 1). Overall (CC, GT and PC combined) foliar N concentrations showed a significant correlation with current-year (year 15) height increment in trees with (R^2=0.41, p<0.0001) and without (R^2=0.36, p<0.0001) vegetation control and indicates that N is limiting conifer growth on this site (Fig. 9). Threshold concentrations of foliar N were estimated from the regression analysis with current height increment and indicate that trees with foliar N concentrations below 0.72% and 0.80% respectively in plots with and without herbicide had significantly poorer increment growth and smaller total height than in trees with N concentrations above those threshold levels (Figs. 10a, 10b). Many trees with poor increment growth had chlorotic foliage, symptomatic of N deficiency. In the CC, GT and PC total height and/or height increment was significantly related with foliar N in plots treated with herbicide, but in untreated plots the relationship was only significant in the GT (Table 2).

Phosphorus concentrations in foliage were also deficient (untreated: 0.030% - 0.109%; herbicide: 0.046% - 0.153%) and were significantly higher in trees treated with herbicide in the CC and GT (Table 1). In contrast the PC foliar P concentrations were highest in the untreated trees. Among the three silvicultural systems the PC had the lowest foliar P concentrations in trees on plots treated with herbicide but had the highest P concentrations in the untreated trees. Foliar P concentrations showed no significant regression effect on height increment or total height with or without vegetation control in any of the silvicultural systems.

N:P ratios, an indicator of the balance between N and P uptake (Ballard and Carter 1985), were significantly lower in trees on plots treated with herbicide in the CC and GT treatments but there was no effect of vegetation control in the PC (Table 1). Among the three silvicultural systems N:P ratios in untreated trees were highest ($p \leq 0.05$) in the CC and lowest in the PC while in trees on plots treated with herbicide the opposite occurred with N:P ratios being highest in the PC. Foliar N:P ratios had a significant effect on height increment and total height in untreated trees in the PC (R^2=0.42, p<0.023) and on total height of trees on plots treated with herbicide in the GT (R^2=0.33, p<0.049). Although there was no effect of N:P ratio on height growth in the CC the large effect of vegetation control on N:P ratios in both the CC and GT systems (Table 1) indicate that P may have been a co-limiting nutrient along with N.

Vaccinium competition

Shrub cover was visually estimated in percent cover classes (<5%, 5%-24%, 25%-49%, 50%-74%, ≥75%) in 7 m^2 plots centered around each sample tree. Vaccinium species (*V. alaskaense, V. ovalifolium*, *V. parvifolium, V. membranaceum*) had by far the largest cover composition in the shrub layer of the CC, GT and PC systems. Shrub cover of Rubus spectabilis was generally sparse and restricted to moister sites. Fireweed although a dominant competitor in earlier years following harvest generally had only sparse cover (<<5%) 15 years after harvest.

Low Vaccinium cover was strongly associated with vegetation control eleven years after herbicide treatments were last applied in 1997, as indicated by the frequency of single tree plots for the three silvicultural systems combined (Figure 11). Vaccinium cover in the large majority of plots treated with herbicide was less than 5% compared to most of the untreated plots that fell into higher cover classes. Although the effect of vegetation control was similar in each of the three silvicultural systems the CC had more plots with less than 5% Vaccinium cover compared to the GT and PC systems. The distance from the conifer stem to the nearest Vaccinium plant confirmed the differences in percent cover and was 2 to 3 times greater in plots treated with herbicide (Figure 12). The CC had lower Vacccinium proximity to conifer regeneration as well as lower Vaccinium cover in plots both with and without vegetation control, a site condition that would be favourable to conifer growth.

Overall (silvicultural systems combined) increasing Vaccinium cover was associated with a progressive decline in mean height increment and total 15-year height of amabilis fir (Figs. 13a,13b), an indication that Vaccinium was interfering with conifer growth on this site. A similar pattern of declining height increment with increasing Vaccinium cover was observed in the CC, GT and PC systems in plots both with and without vegetation control (Figures 14a,14b,14c). Unlike percent cover estimates, conifer proximity to the nearest Vaccinium plant showed no relationship to height growth and is probably not a sensitive enough indicator of Vaccinium abundance.

Natural regeneration density

Density of natural conifer regeneration over 0.5 m in height, primarily western hemlock, amabilis fir, western redcedar, and yellow cedar, was lower in plots treated with herbicide in the three silvicultural systems (Figure 15). Natural regeneration density within the 7 m^2 plots had little effect on planted amabilis fir height increment or total height, except over a high threshold density of about 2.5 trees / m^2 where height growth was suppressed (Figure 16).

SUMMARY & CONCLUSIONS

Annual height increment in amabilis fir declined sharply after 10 years, marking the onset of growth check on the MASS site, and has since remained low. The onset of growth check, which is often coincident with termination of an assart flush following clear-cutting, occurred later than generally reported on other ericaceous shrub dominated sites and the distribution of affected trees was patchy. Herbicide treatments that had been applied in the first 4 years after planting consistently increased annual height increment and continues to have a mitigating effect on growth check in planted amabilis fir eleven years later in the CC, GT and PC systems. Overall, almost half (45%) of the untreated trees (no herbicide applied) exhibited very poor growth with annual increments of 10 cm or less 15 years after planting, compared to only 17% of the trees in plots that had received herbicide. Total height in more than half of the untreated trees was less than 2.5 m after 15 years and will likely result in delayed canopy closure and a longer rotation time. In contrast in plots where herbicide was applied over 90% of the trees were more than 2.5 m in height, most with annual increments over 25 cm. This treatment response supports the silvicultural objectives developed for other ericaceous-dominated forest types to promote canopy closure and shade out or reduce the vigor of ericaceous shrubs (Haeussler et al. 1990, Prescott 1996).

Silvicultural system had a smaller effect on height increment than vegetation control. The CC was somewhat less affected by declining height increment and in plots treated with herbicide had more trees with annual height increments over 40 cm compared to the PC and GT systems. However it is not known whether better height growth in the CC was in response to silvicultural system or more related to inherent (pre-harvest) differences in site quality such as Vaccinium abundance (see below).

Foliar N and P concentrations (current year) were both at deficient levels (Powers 1983) in planted amabilis fir in the three silvicultural systems studied reflecting a decline in foliar N on this site since three years following harvest (unpubl.data). Only foliar N was significantly correlated to annual height increment indicating it was a contributing factor limiting conifer growth on this site. Threshold foliar N concentrations of 0.80% (untreated trees) to 0.72% (trees with herbicide treatment) were associated with a large response in height increment and total height. Phosphorus concentrations were highest in trees growing in plots treated with herbicide in the CC and GT which accordingly had significantly lower N:P ratios than trees in plots without vegetation control. The large effect of vegetation control on N:P ratios in the CC and GT systems indicates that the balance of N and P uptake was affected by competing vegetation and suggests that P is a co-limiting nutrient on this site, since P concentrations were lowest in the poorer growing untreated trees. In the PC it is unclear why P concentrations were highest in the untreated trees, except that proximity to the stand edge was much closer in the smaller cutblocks of the PC and may have had an influence on nutrient dynamics.

Vegetation control continues to have a strong influence on cover of Vaccinium spp., the main shrub competition on this site, eleven years after herbicide treatments were last applied in 1997. The CC tended to have less Vaccinium cover than the GT and PC systems, a site condition favourable to conifer growth. This is consistent with lower pre-harvest cover of Vaccinium spp. in the CC compared to the GT and PC systems reported by Beese et al (200?) and probably does not reflect a treatment level response. Increasing Vaccinium cover was associated with a decline in total height and height increment of amabilis fir in the CC, GT and PC systems in plots with and without vegetation control. Since the Vaccinium was much shorter than the conifer regeneration, competition for light was not a factor suggesting that Vaccinium was interfering with conifer growth on this site either through below-ground competition, interference with nutrient cycling and/or allelopathy as reported for other forest types dominated by ericaceous shrubs ((B. Titus pers. comm.., Mallik 2003). While percent Vaccinium cover was a reliable indicator of poor tree growth, the distance to nearest Vaccinium plant was not related to total height or height increment.

The results of this study indicate that for montane coastal sites conifer foliar N concentrations and Vaccinium cover can be useful indicators for assessing site quality for amabilis fir production and more specifically for diagnosing and predicting the onset of conifer growth check, especially when these indicators corroborate each other. For example post-harvest montane sites where Vaccinium cover is above 5% and foliar N of amabilis fir regeneration is below 0.80% may be more predisposed to growth check. The level of Vaccinium cover in the pre-harvest stand may also give some indication of the susceptibility and expected level of post-harvest colonization (Beese, unpbl. report) which occurs primarily by vegetative spread from rhizomes (Haeussler et al. 1990). Where site conditions indicate a risk to regenerating conifers early treatment with vegetation control can reduce the adverse growth effects from Vaccinium competition.

REFERENCES

Arnott, J.T. and Beese, W.J. 1997. Alternatives to clearcuttinig in BC coastal montane forests. Forest Chronicles,73:679-678.

Ballard, T.M. and R.E. Carter. 1985. Evaluating forest stand nutrient status. B.C. Min. For., Land Manage. Rep. No. 29. 60 p.

Beese, W.J., Sandford, J.S. and Harrison, M.L. 2008. Ten-year vegetation response to alternative silvicultural systems in coastal British Columbia montane ecosystems. Unpublished report.

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

Bradley, R.L., Kimmons, J.P., and Martin, W.L. 2002. Post-clearcutting chronosequence in the B.C. coastal western hemlock zone: II. Tracking the assart flush. J. Sustain. For. 14:23-43.

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

Damman, A.W. 1971. Effect of vegetation changes on the fertility of a Newfoundland site. Ecolog. Monographs 41:253-270.

Dunsworth, B.G. and J.T. Arnott. 1995. Growth limitations of regenerating montane conifers in field environments. *In* J.T. Arnott, W.J. Beese, A.K. Mitchell, J. Peterson. (eds.), Montane Alternative Silvicultural Systems, Proceedings of a Workshop, Courtenay, B.C., 7-8 June 1995. Canada-British Columbia Forest Resource Development Agreement FRDA Report 238, pp.48-68.

Green R.N. and Klinka K. 1994. A field Guide to Site Identification and Interpretation for the Vancouver Forest Region. Ministry of Forests Research Program, Victoria B.C..

Habitat Monitoring Committee,1996. Procedures for Environmental Monitoring in Range and Wildlife Habitat Management. Ministry of Environment Lands and Parks, Ministry of Forests. Victoria B.C..

Haeussler, S., Coates, D., and Mather, J. 1990. Autecology of common plants in British Columbia: A literature review. FRDA report 158, Victoria, B.C.

Hawkins, B.J. and Moran, J.A. 2003. Growth responses of Abies amabilis advance regeneration to overstory removal, nitrogen fertilization and release from Vaccinium competition. For. Sci. 49:799-806.

Husted, L. 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 For., Univ. of B. C., Vancouver, B.C. 123 p.

Jaderlund, A., Zackrisson, O., Dahlberg, A., and Nilsson, M.C. 1997. Interference of Vaccinium myrtillus on establishment, growth, and nutrition of Picea abies seedlings in a northern boreal site. Can. J. For. Res. 27:2017-2025.

Koppenaal, R.S. and A.K. Mitchell. 1992. Regeneration of montane forests in the coastal western hemlock zone of British Columbia: A literature review. Forestry Canada and B.C. Min. For. FRDA Rep. 192. 22p.

Mallik, A.U. 2003. Conifer regeneration problems in boreal and temperate forests with ericaceous understory: Role of disturbance, seedbed limitation, and keystone species change. Crit. Rev. Plant Sci. 22:341-366

Mitchell, A.K., Koppenaal, R., Goodmanson,G., Benton, R., Bown, T. 2007. Regenerating montane conifers with variable retention systems in a coastal British Columbia forest: 10-year results. For. Ecol. Manage. 246:240-250.

Newton, P.F. 1998. An integrated approach to deriving site-specific black spruce regeneration standards by management objective. For. Ecol. Manage. 102:143-156.

Powers, R.F. 1983. Forest research fertilization in California. In T.M. Ballard, S.P. Gessel, and P. Stanley (editors), IURFO Symposium on Forest Site and Continuous Productivity, pp. 388-397. USDA For. Serv. Gen. Tech. Rep. PNW-163. Pacific Northwest Forest and Range Experimental Station. Portland, OR.

Prescott , C.E. 1996. 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.

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

SAS Institute Inc. 1992. SAS/STATR user’s guide. SAS Institute, Cary, N.C.

Thiffault, N., Titus, B. and Munson, A. 2005. Silvicultural options to promote seedling establishment on Kalmiai-Vaccinium-dominated sites. Scand. J. For. Res. 20: 110-121.

Table 1. Foliar N and P concentrations (mean + SE) of amabilis fir in alternative silvicultural systems with and without vegetation control.

Foliar element	Vegetation control Treatment	Silvicultural System			
		Clearcut	Green Tree	Patch cut	*P value*
N (%)	Untreated	0.780 (.020)a / y	0.719 (.047)a / y	0.702 (.023)a / y	*ns*
	Herbicide	0.691 (.035)a / z	0.663 (.035)a / y	0.652 (.022)a / y	*ns*
	P value	*0.0393*	*ns*	*ns*	
P (%)	Untreated	0.065 (.003)a / y	0.074 (.005)a / y	0.079(.004)a / y	*0.0864*
	Herbicide	0.113 (0.005)a / z	0.114 (0.008)a / z	0.067 (0.004)b / z	*<.0001*
	P value	*<.0001*	*0.0003*	*0.0365*	
N:P ratio	Untreated	12.11 (0.62)a / y	10.20 (0.87)ab / y	9.18 (0.80)b / y	*0.034*
	Herbicide	6.20 (0.33)b / z	6.49 (0.96)b / z	10.32 (0.88)a / y	*0.0009*
	P value	*<.0001*	*0.009*	*ns*	

Differences in means between silvicultural systems (columns)are indicated by a,b and between vegetation control treatments (rows) by y, z .
Means followed by the same letter are not significantly different using Tukey' Test.
P values reflect one-way ANOVA between silvicultural systems and vegetation control treatment

Table 2. Significant ($p<0.05$) coefficients of determination (r^2) of foliar N and P concentrations and height growth (Foliar P concentrations vs. height were *not* significant).

Regression	Silviculture System	Treatment	r^2	*p*
%N vs. height increment (year 15)	All (CC, GT, PC)	Untreated	0.36	<0.0001
	All (CC, GT, PC)	Herbicide	0.41	<0.0001
	CC	Herbicide	0.34	0.0459
	GT	Untreated	0.86	<0.0001
	GT	Herbicide	0.54	0.0064
	PC	Herbicide	0.31	0.0626
%N vs. total 15-year height	All (CC, GT, PC)	Untreated	0.26	0.0016
	All (CC, GT, PC)	Herbicide	0.16	0.0145
	GT	Untreated	0.72	0.0005
	GT	Herbicide	0.48	0.0119
	PC	Herbicide	0.34	0.0486
N:P ratio vs. height increment	PC	Untreated	0.42	0.0228
N:P ratio vs. total 15-year height	All (CC, GT, PC)	Herbicide	0.12	0.0357
	PC	Untreated	0.37	0.0360
	GT	Herbicide	0.33	0.0487

FIGURES