Growth of western red cedar seedlings in relation to microtopography, forest floor nutrient status, and fireweed and salal on clear-cut sites in coastal British Columbia

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The growth of western red cedar (*Thuja plicata* Donn) seedlings was studied in relation to microtopography, to forest floor nutrient status, and to fireweed (*Epilobium angustifolium* L.) and salal (*Gaultheria shallon* Pursh) abundance on 4-year-old logged and burned sites dominated by salal on northern Vancouver Island, British Columbia. These relationships were sought to determine some possible factors at the microsite level that influence the growth of western red cedar on recently clear-cut sites. Western red cedar growth and fireweed abundance and height were significantly greater in depressions than on flats and mounds, but these differences were not related to any major differences in forest floor pH, cellulose decomposition, total N and P, and available NH_4^+, NO_3^-, and phosphate P as measured using resin bags. The ecological significance of and possible reasons for the lack of correlation found between (*i*) western red cedar and fireweed growth and (*ii*) many measures of forest floor nutrient status are discussed.

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La croissance du cèdre rouge de l'ouest (*Thuja plicata* Donn) fut examinées en relation de la microtopographie du sol, plusieurs variables du sol et de l'épilobe (*Epilobium angustifolium* L.) et de salal (*Gaultheria shallon* Pursh) sur des parterres de coupe de 4 ans dominés par salal au nord de l'Île de Vancouver, Colombie-Britannique. Ces relations furent étudiées de façon à déterminer au niveau du microsite les facteurs possibles qui influencent la croissance du cèdre rouge de l'ouest sur des jeunes parterres de coupe. La croissance du cèdre rouge de l'ouest et la distribution et la hauteur de l'épilobe étaient significativement plus grandes dans les dépressions que sur les plats et monticules. Ces différences n'étaient pas corrélées avec le pH du sol, la décomposition de la cellulose, la quantité totale de N et P et la disponibilité en NH_4^+, NO_3^- et P-phosphate telle que mesurée par la méthode de sac de résine entre les trois positions microtopographiques. La signification écologique et les raisons possibles du manque de corrélation entre (*i*) la croissance du cèdre rouge de l'ouest et de l'épilobe et (*ii*) plusieurs facteurs du sol sont discutées.

Introduction

The forest floor and surface soil horizons of a forest or a clearcut are often highly variable in microelevation, microscale chemical properties (Beatty and Stone 1986), and macromorphology (Klinka *et al.* 1981). This small-scale heterogeneity (i.e., square metre and metre scales) has often been ignored in site research, which has focussed on larger scale (i.e., hectare and 100-m scales) gradients in the environment (Beatty 1984). Microscale heterogeneity of the forest soil has been attributed to tree falls (Beatty and Stone 1986), mounds and pits (Ruel *et al.* 1988), decaying wood (Quesnel and Lavkulich 1981; Sidle and Shaw 1983), variations in overstory canopy species composition (Turner and Franz 1986; Beatty 1984; Zinke 1962; Boerner and Koslowsky 1989), and distance from individual trees (Lodhi, 1977). Improved growth of individual trees in clearcuts has also been associated with more fertile microsites (Husted, 1982; Adams 1974).

On the northern part of Vancouver Island in coastal British Columbia, on clearcuts originating from old-growth western red cedar (*Thuja plicata* Donn) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), early height growth of planted and natural western red cedar seedlings is generally poor and highly variable (i.e., 10–40 cm height growth per year). Although some of this variability may be explained by variation in stock quality, seedling genotype, and handling and planting of seedlings, it is hypothesized that small-scale differences in site quality and competing vegetation are also important. Genetic variability in western red cedar is believed to be small (Bower and Dunsworth 1988). Patchy distribution of fireweed (*Epilobium angustifolium* L.) on these sites could also indicate differences in site quality at the microsite level.

The objective of this study was to relate microtopography to western red cedar seedling growth, to some measures of forest floor nutrient status, and to fireweed and salal (*Gaultheria shallon* Pursh) abundance on 4-year-old logged and burned sites dominated by salal on northern Vancouver Island, British Columbia. A better understanding of the microsite factors that influence western red cedar seedling growth may help to identify factor(s) that limit early conifer seedling growth on these sites.

The following three hypotheses were addressed: (*i*) depressions have greater forest floor nutrient concentrations than mounds; (*ii*) the growth of western red cedar is related to the nutrient status of the upper forest floor immediately surrounding its roots; and (*iii*) the abundance and height of fireweed are related to the forest floor nutrient status at the microsite level.

The first hypothesis is based on personal observations that western red cedar growth and fireweed abundance and height are greater in depressions than on mounds, and that these differences are due to greater forest floor nutrient concentrations. The second hypothesis tests the idea that better growth of individual conifer trees can be related to greater soil

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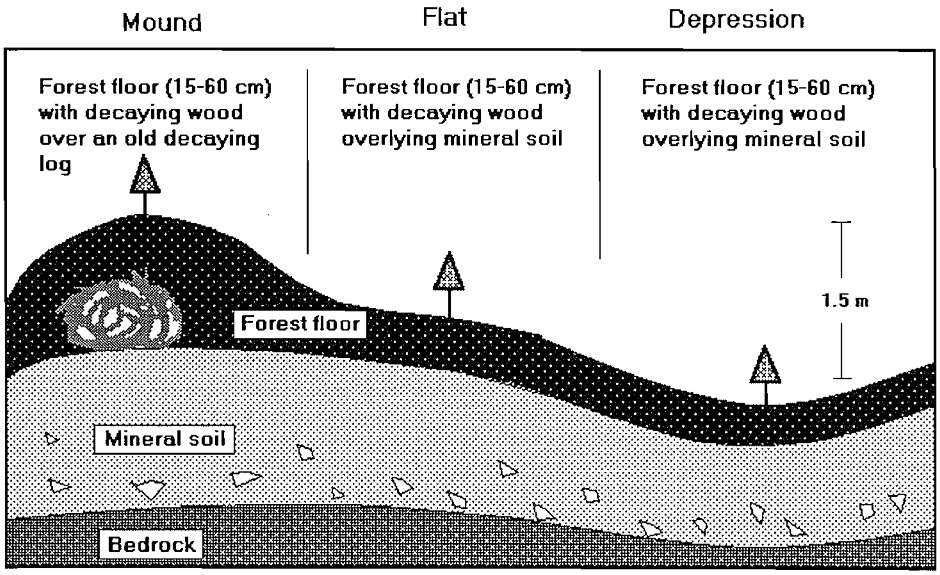

FIG. 1. Cross-sectional diagram depicting the microtopography and variety of surface substrates commonly associated with the three forest floor microtopographic patterns described in this study.

nutrient status at the microsite level (Husted 1982; Adams 1974). Finally, the third hypothesis arises from the reports by Tamm (1956) and Ruwet (1980), among others, that the abundance and height of fireweed indicate a good supply of nutrients, especially N. All hypotheses were tested in the field using microsite plots centered around 3-year-old western red cedar seedlings.

Study area

The study area was located between Port McNeill and Port Hardy in the CWHb$_{vm}$ variant of the Coastal Western Hemlock biogeoclimatic zone (Green *et al.* 1984) on northern Vancouver Island, British Columbia, Canada (50°60′N, 127°35′W). The study was conducted in a landscape unit described by Lewis (1982) as the undisturbed phase of the old-growth western red cedar – western hemlock ecosystem (CH phase). Following logging, this ecosystem phase experiences rapid reinvasion by salal from rhizomes that are present in the old-growth forest prior to logging. The CH phase has a thick (15–60 cm), compacted humus form rich in decaying wood (lignohumimor; Klinka *et al.* 1981) over a moderately well to somewhat imperfectly drained Folisol. Following logging, this ecosystem phase is easily recognizable by the presence of large western red cedar stumps (2–3 m in diameter).

The study area has a gently undulating topography rarely exceeding 300 m in elevation. Surface materials consist of deep (>1 m), unconsolidated glacial moraine and fluvial outwash materials. The area receives approximately 1700 mm of rain annually, with 65% of the precipitation occurring between October and February. Although the summer months experience less rainfall than the winter months, growing-season rainfall is thought to be sufficient to prevent any soil moisture deficit (Lewis 1982). The number of hours of sunshine varies from an average high of 6.4 h/day in July to an average low of 1.5 h/day in December; these low values reflect the frequent occurrence of fog in the summer and frontal clouds in the winter. Mean daily temperature ranges from a low of 3.0°C in January–February to a high of 13.7°C in July–August. All weather data were obtained from the Port Hardy Airport weather station located within 18 km of the study area.

The study was conducted in two different areas that had been clear-cut in 1985 and slashburned in 1986. The harvesting technique (cable logging) minimized site disturbance, so that the microtopographic pattern was not altered significantly. The two cutovers were both moderately well drained and situated within 1.5 km of each other.

Materials and methods

Microsite selection

Western red cedar seedlings, planted 2 years previously as part of the control treatment of another experiment, were randomly selected in the spring of 1989 as the center of 20 microsite plots per cutover, for a total of 40 microsite plots. The microsite plots were then classified into three microtopographic positions: mounds, flats, and depressions (Fig. 1). Mounds and depressions were defined as being at least 0.5 m above and below the mean ground level, respectively. Plots at mean ground level were classified as flats. The vertical distance between mounds and depressions varied between 1.0 and 1.8 m. Because western red cedar seedlings were not planted within 1 m of stumps, the mounds in this study are never associated with stumps.

Western red cedar, fireweed, and salal vegetation

The total height and root-collar diameter of each western red cedar seedling were measured at the beginning (April) and at the end (September) of the 1987, 1988, and 1989 growing seasons. The percent cover of fireweed and salal in 1-m^2 plots centered on the western red cedar seedlings was estimated visually in July 1989. The total height of each fireweed stem was measured within each plot at the end of August 1989.

Forest floor factors

Four forest floor cores (7.4 cm in diameter) were collected to a depth of 15 cm from equally spaced sampling spots within 20 cm of each seedling at the end of September 1989. These were bulked to form one soil sample per seedling. Only the upper 15 cm of the forest floor was sampled because Messier (1991) found most of the roots of western red cedar seedlings and fireweed to be in this upper layer. Forest floor pH was determined from fresh samples passed through a 2-mm sieve. Forest floor pH was determined with a glass electrode in distilled water using a soil–water ratio of 1:4 (w/v). A subsample was oven-dried at 70°C for 24 h to determine the moisture content. All the results are reported on an ovendry basis. Total N and P were obtained by digesting 0.2 g (ovendry mass) of forest floor material overnight in a mixture of potassium sulfate, sulfuric acid, and selenium in a block digester. Total N and P analyses were conducted on a

TABLE 1. Comparison of different forest floor variables between the three microtopographic positions: mounds, flats, and depressions

Microsite variables	Microtopographic positions			Min. value	Max. value
	Mounds	Flats	Depressions		
Cellulose decomposition (%)	12.8*a* (1.9)	14.9*a* (2.8)	13.5*a* (1.4)	1.2	52.0
Resin NH_4^+ (mg/g of resin)	0.156*a* (0.016)	0.149*a* (0.010)	0.155*a* (0.016)	0.05	0.25
Resin NO_3^- (mg/g of resin)	0.003*a* (0.001)	0.002*a* (0.000)	0.002*a* (0.001)	0.000	0.006
Resin phosphate P (mg/g of resin)	0.140*a* (0.023)	0.119*a* (0.017)	0.151*a* (0.037)	0.02	0.34
pH	3.93*a* (0.08)	4.43*a* (0.27)	4.20*a* (0.12)	3.61	4.89
Organic matter (%)	93.2*b* (1.8)	88.8*b* (3.3)	78.2*a* (5.2)	45.3	98.3
Total N (%)	0.81*a* (0.04)	0.86*a* (0.06)	0.87*a* (0.09)	0.45	1.45
Total P (%)	0.041*a* (0.003)	0.044*a* (0.004)	0.057*a* (0.013)	0.025	0.180
C:N ratio	69.1*b* (4.3)	64.2*b* (4.7)	54.7*a* (3.3)	33.0	95.6
Decaying wood within first 40 cm (%)	36*b* (7.5)	26*ab* (6.3)	21*a* (6.1)	5	90
No. of microsite plots	8	20	12		

NOTE: Values in parentheses are 1 SE of the mean. Numbers in rows followed by the same letter are not significantly ($P > 0.05$) different between microtopographic positions.

Technicon AutoAnalyser II (Technicon Instrument Corp., Tarrytown, NY) using standard procedures. Soil organic matter content was determined by loss on ignition (24 h at 500°C), and carbon content was calculated by dividing the percent organic matter by 1.724 (Armson 1977).

In early May 1989, mixed cation (21 g, 68% moisture, Amberlite IRC-50 CP RCOO—H—) and anion (29 g, 65% moisture, Amberlite IRC-45 CP RNH_3^+OH—) exchange resin enclosed in two different stocking bags, and two cellulose discs (4.25 cm diameter Whatman No. 1) enclosed in two different 1-mm nylon mesh bags, were buried for 2 months at 15 cm in the forest floor 20 cm on each side of each seedling to estimate the relative nutrient availability and decomposition rate in the upper 15 cm of the seedling's root environment. The resin-mixture bags had cation and anion exchange capacities of approximately 33 mequiv. each. To prevent microbial growth on the resin, approximately 4% of the exchange capacity of the resin was loaded with mercuric chloride ($HgCl_2$). Laboratory and field studies have shown a good correlation between the ion-exchange resin bag method and many conventional methods of assessing nutrient availability (Binkley and Matson 1983; Binkley *et al.* 1986; Lajtha 1988). Moreover, it is hypothesized that *in situ* ion-exchange resin bags may behave similarly to plant roots in terms of ion uptake (Gibson 1986), and be sensitive to microenvironmental conditions that influence N availability (Binkley and Matson 1983). After 2 months, the resin was air dried, removed from the bags, and shaken with 200 mL 1 M KCl for 1 h, and the extract was analyzed for NH_4^+, NO_3^-, and phosphate P as described above. The cellulose discs were cleaned in distilled water and then dried at 70°C for 24 h to determine mass loss.

In October 1989, the soil surrounding each seedling was excavated to a depth of 40 cm, and the rooting substratum was described in terms of percentage of the profile containing mineral soil and decaying wood.

Statistical analyses

One-way analysis of variance was used to compare western red cedar seedling growth, fireweed abundance and vigour, forest floor variables, and salal abundance between the three different microtopographic positions. Tukey's honestly significantly different multiple comparison test was used to compare the treatments' means. The data were checked for both homogeneity of variances and normality of distribution. No transformations were required. Multiple correlation analyses (using the Pearson correlation matrix) were used to estimate the degree of association between any pair of variables. A probability test for each correlation coefficient was also performed (Wilkinson 1988).

Results and discussion

No significant differences in forest floor pH, cellulose decomposition, total N and P, and resin NH_4^+, NO_3^-, and phosphate P were found between the three microtopographic positions (Table 1; P varied from 0.15 to 0.76 for all variables). These data indicate that the microtopographic pattern found on our study sites does not induce any major differentiation in the upper forest floor nutrient concentrations as revealed by the measurements we made. This finding does not support our first hypothesis. It is possible, however, that some differences occur at a greater depth than the one sampled in this study.

No evidence was observed on our study sites that the major agent responsible for the formation of depressions and mounds was windthrow. A comparison of the rooting substratum in the upper 40 cm of the forest floor between the

TABLE 2. Pearson correlation matrix for western red cedar height and diameter increment, salal abundance, fireweed abundance and vigour, and soil variables

	1	2	3	4	5	6	7	8	9	10	11
(1) Ht. increment of cedar	1.00										
(2) Diam. increment of cedar	0.71***	1.00									
(3) Salal cover	−0.27	−0.31*	1.00								
(4) Fireweed cover	0.61***	0.41*	−0.37*	1.00							
(5) Fireweed ht.	0.42**	0.19	−0.16	0.57***	1.00						
(6) Cellular decomposition	0.24	0.21	−0.39*	0.21	0.33*	1.00					
(7) Resin NH_4^+	−0.16	−0.17	−0.03	0.01	0.20	−0.27	1.00				
(8) Organic matter	−0.42*	−0.15	0.32	−0.19	−0.36	−0.49*	0.06	1.00			
(9) Total N	0.18	0.28	0.58**	0.04	−0.12	−0.24	−0.29	0.37*	1.00		
(10) Total P	0.19	0.03	0.22	−0.03	−0.13	−0.19	−0.28	0.16	0.61**	1.00	
(11) C:N ratio	−0.42*	−0.40	0.38	−0.18	−0.09	0.06	0.48*	0.27	0.70**	0.17	1.00

*$P = 0.05$.
**$P = 0.01$.
***$P = 0.001$.

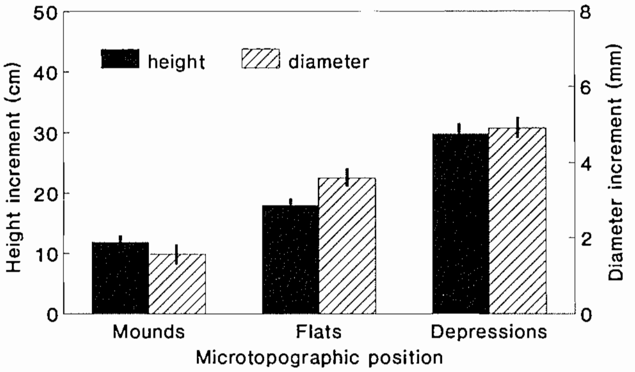

FIG. 2. Comparison of height and diameter increments of western red cedar seedlings in 1989 (3 years after planting) between mounds, flats, and depressions. Vertical bars represent 1 SE of the mean.

three different microtopographic positions indicated mounds to be more often associated with decaying wood than depressions (Table 1). This is consistent with the observation of higher organic matter and C:N ratio in forest floor (in the upper 15 cm) of mounds compared with that of depressions (Table 1). A survey made in clearcuts and old-growth forests indicated that this microtopographic pattern is often related to the distribution and accumulation of large pieces of decaying logs on the forest floor (Fig. 1). This would explain the greater proportion of decaying wood found in the upper 40 cm of the forest floor in mounds compared with in depressions. Further research is needed, however, to ascertain such observation.

Western red cedar height and diameter increments in 1989 (the 3rd year after planting) were significantly ($P < 0.05$) greater in depressions than on flats and mounds (Fig. 2). There was an upward trend in both growth variables from mounds to depressions, the difference being about 2.5 times. Differences in growth increments between the three microtopographic positions became apparent in 1988, 2 years after planting. However, these differences in western red cedar growth are not related to any of our measures of forest floor nutrient status (Table 2). This finding does not support our second hypothesis. Other edaphic or microclimatic factors not investigated in this study are probably involved in explaining the marked differences in the growth of western red cedar seedlings between microtopographic positions reported in Fig. 2.

Moisture was not measured in this study, but it has not been found to be a factor limiting conifer growth on these sites (Messier and Kimmins 1991). We observed, however, that western red cedar seedlings growing in fully exposed locations often turn brown for the first 2 years following planting, whereas those partially protected by vegetation and microtopography maintain a green appearance. Even after 3 years, some of the seedlings growing on the mounds were still not as green as the ones in the depressions. This browning effect likely affects photosynthesis and ultimately the growth of western red cedar seedlings. We are unaware of any research on this subject, however.

Studies examining relationships between tree growth and soil properties immediately surrounding individual trees report contrasting results. Husted (1982) compared the soil properties surrounding well and poorly growing Pacific silver fir (*Abies amabilis* (Dougl.) Forbes) saplings in recently clear-cut sites on eastern Vancouver Island, Canada. Forest floor associated with trees showing good growth had significantly higher total N and exchangeable Mg, and a lower C:N ratio, compared with forest floor associated with the poorly growing trees. Similarly, Adams (1974) found a higher soil total N under faster growing 7- to 40-year-old Sitka spruce (*Picea sitchensis* (Bong.) Carr.) trees compared with under slower growing trees. The differences in soil properties between the faster and slower growing trees in these two studies were fairly small, however, and could have been induced by the trees themselves. Shaw *et al.* (1987) found no difference between the growth of Sitka spruce seedlings planted in rotten wood and those planted in undisturbed forest floor materials in southeast Alaska, although large differences in soil nutrient status were found between the two types of microsites (Sidle and Shaw 1983). It appears very difficult, based on this study and those mentioned above, to relate the growth of conifers to the forest floor nutrients immediately surrounding individual trees. Conifers are capable of producing very extensive root and mycorrhizal systems and may not be completely dependent on the soil nutrients immediately surrounding them.

The interpretation of our results in terms of the nutritional requirements of western red cedar is difficult since there is very little information available on western red cedar nutrition (Weetman *et al.* 1988). Western red cedar is found on a wide variety of sites in the Pacific Northwest, but grows best on

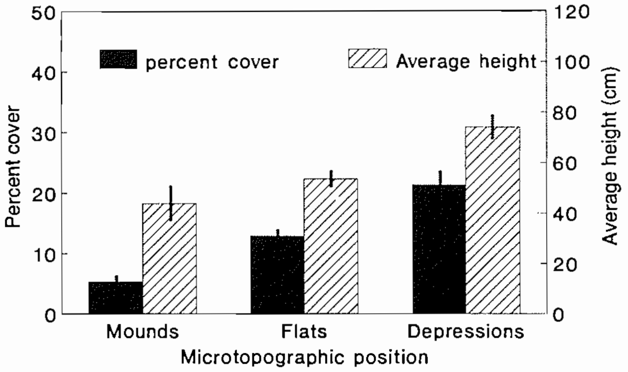

FIG. 3. Comparison of percent cover and average height of fireweed between mounds, flats, and depressions. Vertical bars represent 1 SE of the mean.

wet, nutrient-rich sites (Krajina *et al.* 1982). Krajina *et al.* (1973) found western red cedar to grow better with N supplied as NO_3^- than as NH_4^+. Western red cedar has been found to respond to N–P–K fertilization in coastal British Columbia (Weetman *et al.* 1989). However, Messier (1991) found 1- to 3-year-old western red cedar seedlings to be unresponsive to any treatments that either increase or decrease many measures of forest floor nutrient availability on different sites on northern Vancouver Island. Further research is required to ascertain the nutritional requirement of western red cedar on edaphically different sites.

Fireweed was significantly ($P < 0.05$) more abundant and taller in depressions than on flats and mounds (Fig. 3). The differences in percent cover were substantial, going from an average of 5% on mounds to 20% in depressions. These differences in fireweed abundance and height cannot be explained in terms of the forest floor variables that were measured (Table 2); the correlation between fireweed average height and NH_4^+ availability (resin NH_4^+) was particularly weak ($r = 0.2$). These findings do not support our third hypothesis. The small differences in percent organic matter and C:N ratio appear insufficient to explain the marked differences in fireweed abundance and height between depressions and mounds.

These results are consistent, however, with those of van Andel (1976), van Andel *et al.* (1978), and van Andel and Nelissen (1979), who stated that fireweed can tolerate and grow on a wide variety of soil conditions and should not be considered a good indicator of N availability. According to van Andel (1976), its increase in abundance following fertilization or burning could be attributed to its ability to tolerate the newly created conditions rather than indicating a high nutrient requirement. In effect, fireweed produces long rhizomes that accumulate large quantities of carbohydrates and nutrients over the years, and its growth for any particular year may not be dependent on the soil nutrient status immediately surrounding its shoots. Myerscough (1980), reviewing the literature on fireweed, stated that the successful establishment of this species on recently disturbed sites appears to be limited to open moist sites of at least moderate fertility, and little initial vegetative competition.

Salal cover varied from 2.5 to 85% within the forty 1-m^2 microsite plots, but only a very weak negative correlation was obtained between western red cedar growth and salal cover (Table 2). This finding supports the contention that western red cedar is little affected by the presence of salal (Messier 1991).

Conclusion

No significant differences in our measures of upper forest floor nutrient concentrations were found between the three microtopographic positions investigated in this study. It is possible, however, that some differences in nutrient availability between mounds and depressions occur at greater depth than the upper 15 cm sampled in this study.

Western red cedar growth and fireweed abundance and height were greater in depressions than on mounds. This suggests that small depressions on these sites constitute good planting microsites for western red cedar; more research is needed, however, to ascertain why this is so.

No correlations were found between (*i*) western red cedar height and diameter increments and (*ii*) our measures of forest floor nutrient concentrations. This lack of correlation may have been due to (*i*) the methods and methodology used in this study and (or) (*ii*) the selection of western red cedar as the bioindicator species. In effect, Messier (1991) found 1- to 3-year-old western red cedar seedlings growing on these same sites to be little affected by any treatments that increase or decrease many measures of forest floor nutrient availability. Sitka spruce or western hemlock seedlings might have given better results, since Messier (1991) found them sensitive to changes in forest floor nutrient availability.

The lack of correlation between (*i*) fireweed abundance and height and (*ii*) our measures of forest floor nutrient status suggests that fireweed growth is not directly influenced by the availability of nutrients found 4 years after logging and burning on our study sites.

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