RESEARCH REPORT

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Twenty-year Interior Spruce Tree Growth and Nutrient Levels on Calcareous Soils in Southeastern British Columbia

D.G. Maynard and M.P. Curran

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Prepared by
Mike Curran
B.C. Ministry of Forests and Range
Southern Interior Forest Region
1907 Ridgewood Road
Nelson, BC V1L 6K1

Doug Maynard
Natural Resources Canada
Pacific Forestry Centre
506 W Burnside Road
Victoria, BC V8Z 1M5

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ABSTRACT

Twenty-year growth results reported for a series of trial sites in southeastern British Columbia indicated that interior spruce progeny, regardless of seed origin, grew faster (32%, on average) and survived better (8%, on average) on acidic soils than on calcareous (high pH) soils. This previous study indicated that the soil chemical conditions (including calcareous soils) appeared to have considerable influence on the growth and survival of interior spruce. We investigated the soil relationships further on these sites in the current study. We could not explain a mechanism to account for the poorer tree growth, nor elucidate a regional trend regarding the specific influence of calcareous material on nutrient availability and/or how it may influence tree growth. However, trends (albeit insignificant due to within-site variability) were apparent on shallow calcareous soils, such as at the East White River site, where the carbonates were present within 30 cm of the surface and there was a trend for poorer growth when the trees were growing in these soils. There was no clear indication if nutrient deficiencies or imbalances were the cause. We also observed that the strength of carbonate (i.e., % $CaCO_3$) was also greater on the shallower depth to carbonate sites. However, at the Lussier River site, where carbonates were on average deeper than at East White River, there was no trend in tree growth related to carbonate depths. Comparisons of the foliage chemistry between the two calcareous sites and an acidic site showed higher calcium (Ca) and magnesium (Mg) concentrations in the foliage from the calcareous sites; however, no differences appeared to be related to a carbonate-induced nutrient deficiency. We hope studies under way on fertilizer trials and the Long-Term Soil Productivity (LTSP) network sites in the East Kootenays will provide further insight into the role of carbonates on tree growth and the sensitivity of calcareous soils to disturbance. This study adds to the knowledge base, indicating that shallow calcareous soils are more sensitive to disturbance. Thus, management practices that minimize the potential detrimental effects of forest operations on calcareous soils should be implemented.

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INTRODUCTION

Many soils in the southern Rocky Mountain Trench and Rocky Mountains in British Columbia are calcareous (limestone-derived and of high pH), fine textured, and susceptible to compaction during elevated soil moisture conditions. The disturbance of calcareous soils, particularly the displacement of the shallow, more fertile topsoil and exposure of the unfavourable, high-pH, calcareous subsoil, has been the subject of a number of studies (Kishchuk et al. 1999; Kishchuk 2000).

In a 20-year-old progeny trial in the East Kootenays, all progeny, regardless of their source, grew best on acidic (East Kootenay Acidic [EKA]) rather than calcareous (East Kootenay Calcareous [EKC]) soils (Xie et al. 1998). Similar results for white spruce were reported for Ontario (Teich and Holst 1974). Xie et al. (1998) reported that differences among sites accounted for 33–48% of the growth variation. The EKA sites averaged 32% better growth than the EKC sites and had greater survival (8%), regardless of tree origin. Depth to carbonates was not reported.

Dumanski et al. (1972) found that productivity of lodgepole pine in the foothills of Alberta decreased with increasing pH, where soil pH > 5.5. However, the soil depth where the pH was measured was not reported. Other studies have made correlations between carbonates and productivity: either with tree growth (lodgepole pine in the Alberta Foothills) (Duffy 1964) or amount of calcium carbonate ($CaCO_3$) at a given depth (25–50 cm) to site index (Douglas-fir in central Italy) (Corona et al. 1998).

In the study of Xie et al. (1998), sites were designated as acidic (EKA) or calcareous (EKC) based on the site locations (i.e., west side of the Rocky Mountain Trench acidic, east side calcareous). No soil data were reported nor were there any indications of significant soil disturbances. Studies on growth limitations related to calcareous soils have not differentiated between the potential effect of the carbonates themselves, soil disturbance (i.e., compaction or displacement), or a combination of both (Smith and Wass 1994a).

The general objective of this study was to determine if calcium carbonate was a limiting factor in the growth of 20-year-old interior spruce. The specific objectives were:

- to describe the soil conditions for the acidic (EKA) and calcareous (EKC) soil groupings for the progeny test sites studied by Xie et al. (1998);
- to determine the relationship of 20-year-old interior spruce growth with depth to carbonates at two calcareous sites within the former Invermere Forest District;
- to determine the relationship of soil and foliar chemistry to interior spruce growth at the two calcareous sites; and
- to compare the foliage chemistry of interior spruce growing on calcareous soils to interior spruce growing on a non-calcareous soil.

MATERIALS AND METHODS

Progeny trials set up in 1975 in the East Kootenays by the British Columbia Forest Service (BCFS) were used (Xie et al. 1998). The original study established 14 sites in southeastern British Columbia (a 15th site was established at Red Rock near Prince George). Four sites had poor survival and were not considered in the original study or our study. A fifth site, located at Grave Creek, was also not included because it was accidentally thinned in 1988 (Xie et al. 1998). Soils in this area have previously been found to have carbonates at depth (Dykstra and Curran 2000).

Of the remaining nine sites, eight were located and evaluated for the presence or absence of carbonates and depth of carbonates (Table 1). At all sites, at least two soil pits were dug. If carbonates were present, the depth to carbonates was measured.

Due to access constraints, we were unable to sample the ninth site, Roche Creek, located in the southeastern part of the Kootenays. This site was designated EKC and had the best growth of any of the EKC sites (Xie et al. 1998). However, reconnaissance-level soil mapping by Lacelle (1990) designated all soils in the Roche Creek drainage as acidic. It was not included in our analysis.

TABLE 1 *Soil horizon (last or first calcareous), pH, and presence or absence of carbonates at spruce progeny trials studied by Xie et al. (1998)*

Site	Horizon[a]	Depth (cm)	Presence of CO_3	pH($CaCl_2$)
Acidic sites				
Perry Creek	C	47+	nil	4.30
Jumbo Creek (side slope)	C	41–50+	nil	6.24
Jumbo Creek (fluvial)	CIII	49–54+	nil	5.36
Horsethief Creek (side slope)	CII	33–52+	nil	6.42
Horsethief Creek (fluvial)	CIV	55–62+	nil	6.30
Bloom Creek	C	39–44+	nil	5.62
Calcareous sites				
Windermere Creek (pit one)	BCk	33–42	strong	7.44
Windermere Creek (pit two)	BCk	33–49	strong	7.42
Lodgepole Creek	Ck	53–60+	strong	7.42
Lodgepole Creek (fluvial)	Ck	64–71+	moderate	7.25
Detailed study sites				
Lussier	various	31.0 (median)	strong	variable
East White River	various	21.5 (median)	strong	variable

[a] The C horizon is parent material unaffected by soil forming processes. The B horizon is characterized by enrichment in organic matter, sesquioxides, or clay; or by development of soil structure; or by a change in colour. The BC is transition between B and C. The subscript k denotes the presence of carbonates as indicated by visible effervescence when dilute HCl is added. Roman numerals indicated different parent material (Watson 2007).

Two calcareous sites, East White River and Lussier River, were sampled in detail (Table 2). A third site (west side of the Rocky Mountain Trench at Horsethief Creek) was used as an acidic comparison and sampled only for foliar chemistry.

TABLE 2 *The location and general soil properties of East White River and Lussier River*

	Location	Elevation (m)	Soil classification (association[a])	Biogeo-climatic unit	Median depth to carbonates (cm)	Range of depth to carbonates (cm)
East White River	lat 50°15′N, long 115°10′W	1524	Orthic Eutric Brunisol[b] Moscliffe (MW4) assoc.	ESSFdk	21.5	1–51
Lussier River	lat 50°00′N, long 115°32′W	1554	Orthic Eutric Brunisol Gagnebin (GB1) assoc.	ESSFdk	31.0	16–54+

a These soil associations and classifications are described in Lacelle (1991).

b The Orthic Eutric Brunisol of the Moscliffe (MW4 component) is the less common soil. The most common soil is a Brunisolic Gray Luvisol.

At the three sites selected for detailed study, 15 progeny were randomly selected for study of depth to carbonates and nutrients. The only selection criterion used was that the progeny had to be present in both blocks of the three sites.

There were two blocks per site and two trees per progeny sampled at each block for a total of 60 trees per site. Rows of 10 trees were initially planted for each progeny per block. Two trees within a row were sampled. If a tree at the row location selected was missing or dead then the next tree was sampled. The BCFS Research Branch (C.-Y. Xie) kindly provided tree growth data for the sample trees.

Individual trees were sampled for foliage analysis at all three sites. Current year foliage from the two uppermost whorls was sampled. Sampling occurred in mid-September in both years of this study. Samples were collected in paper bags and allowed to air dry. Samples were oven-dried at 60 °C for 24 h. One hundred whole needles were weighed to determine 100-needle weight.

Samples were then ground in a Wiley mill to pass through a 0.25-mm sieve.

Total elemental analysis of the foliage was done on oven-dried samples (60°C for 24 h). Total nitrogen (N) was determined on a LECO FP-228 organic N determinator. Total elemental concentrations of phosphorus (P), sulfur (S), calcium (Ca), magnesium (Mg), potassium (K), manganese (Mn), iron (Fe), zinc (Zn), copper (Cu), boron (B), and sodium (Na) were determined by an inductively coupled plasma atomic emission spectrometer (ICP-AES) following acid digestion with HNO_3-H_2O_2-HCl in a microwave oven (Kalra et al. 1989).

Soil was sampled within the rooting zone of the trees at the East White and Lussier River sites. The depth of the surface organic horizon and depth to carbonates (if present) were determined. The presence of carbonates was tested by dripping 10% HCl onto a soil sample. Effervescence indicated the presence of carbonates and the degree of effervescence indicated the strength of the carbonates (Watson 2007). The surface organic horizon and mineral soil samples were collected from above the calcareous horizon. If a carbonate horizon was present it was also sampled. Soils were sampled in the last week of August.

Soil samples were kept cool until returned to the laboratory, then air-dried. The pH was determined on air-dried samples in 0.01 M $CaCl_2$. Exchangeable cations and cation exchange capacity (CEC) were extracted with unbuffered 1.0 M NH_4Cl using a mechanical vacuum extractor (Kalra and Maynard 1991). Extractable Ca, Mg, K, S, Mn, and Na were analyzed by an ICP-AES. The CEC was determined by the NH_4^+ displacement method. The displaced NH_4^+ was determined with a Technicon autoanalyzer II (Kalra and Maynard 1991). A LECO CR 12 C analyzer determined total soil carbon (C). Carbonates were determined using a modified LECO method of Wang and Anderson (1998). Total soil C was determined by setting the furnace temperature at 1100°C. Organic C was determined using a furnace setting of 840°C. The difference between the two was considered carbonate-C and is reported as percent calcium carbonate equivalent (% $CaCO_3$). Total soil N was determined using the same method as for the foliage.

The ANOVA design and methods followed a similar dataset design presented by Nemec (1992). The soil parameters were analyzed separately for each site as a randomized complete block design. Data were analyzed using the general linear model procedure (proc GLM) in SAS (SAS Institute Inc. 2004). Growth attributes, soil properties, and foliar nutrients were compared among depth to carbonates and provenances. Least square means was used to compare means among depth to carbonate classes and provenances.

A forward stepwise multiple linear regression was used to estimate the variability in height, dbh (diameter at breast height), volume, and 100-needle weights for interior spruce at East White River that was explained by depth to carbonates and soil and foliar chemistry.

RESULTS AND DISCUSSION

CORROBORATION OF SITE DESIGNATIONS

The interior spruce progeny sites were broadly classified as either EKA or EKC based on their location within the Rocky Mountain Trench (Xie et al. 1998). The depth to carbonates (if present) and pH of the mineral horizons at eight of the nine progeny sites (from Xie et al. 1998) located in the East Kootenays were determined (Table 1; see more detailed soil profiles in Appendix 1). The EKA or EKC designation of the sites by Xie et al. (1998) was corroborated by soil analysis, with the exception of Roche Creek (not sampled).

Xie et al. (1998) observed that trees at the acidic zone sites grew faster (on average, 32%) and survived better (8%, on average) than trees in the calcareous zone sites. The depth to carbonates varied considerably among the four calcareous sites (from 21 cm at East White River to about 58 cm at Lodgepole Creek). Duffy (1964) indicated that, in even-aged lodgepole pine (60-year-old), depth to carbonates accounted for a small but significant portion of the variation in tree height and volume sampled at 37 sites in the Alberta Foothills. Obviously, there were too few calcareous sites to carry out a similar correlation of growth with depth to carbonates in our study. There was, however, considerable variation in the depth to carbonates within sites. The second part of this study was initiated to determine if there was a relationship between carbonate depth and tree growth within a site.

East White River

The East White River site was in the EKC zone as defined by Xie et al. (1998). On average, spruce growth was lower at this site than at similar sites in the EKA zone. In the overall experiment, Xie et al. (1998) found among-family differences accounted for 9–19% of the total variation observed in the growth measurements for the entire experiment. An ANOVA comparing the growth of the 15 progeny trees sampled in our study found no significant difference among the 15 sampled progeny at East White River.

Soil properties

The median depth to carbonates at East White River was 21.5 cm but carbonates were found over a wide range of depths (1–54 cm). Trees were grouped based on the depth to carbonates: shallow (0–15 cm [mean depth = 12.6 cm]; 12 trees), medium (16–30 cm [mean depth = 21.0 cm]; 35 trees), and deep (31–45+ cm [mean depth = 32.5 cm]; 13 trees). The percent carbonate ($CaCO_3$) equivalent was similar for the 0–15 cm and 15–30 cm depth classes (52.7 ± 20.7% and 46.3 ± 20.8% $CaCO_3$). In the 30–45 cm depth class, the percent $CaCO_3$ equivalent was about half (27.5 ± 19.8%) of the shallower depth classes. The shallower depth to carbonate microsites have less volume of surface acidic soil and more severe carbonate levels closer to the surface. In a study of the relationship between environmental factors and site index of Douglas-fir, $CaCO_3$ content in the 25–50 cm soil depth accounted for about 11% of the variability in growth (Corona et al. 1998). Therefore, it may be that both the depth to carbonates and the carbonate strength are important factors affecting tree growth.

The growth attributes of interior spruce by carbonate depth class are given in Table 3. The four growth attributes of the 0–15 and 16–30 cm depth classes were similar. However, in the 31–45+ cm depth class, growth attributes were 13–38% higher than in the shallower depth to carbonate classes; however, these differences were not statistically significant. The large variability in growth within the depth to carbonate classes made the differences statistically non-significant, but all growth attributes showed a similar trend.

TABLE 3 *The 100-needle weight, height, dbh, and volume of interior spruce by depth class to carbonates at East White River. Values are means ± standard deviations.*

	Carbonate depth classes		
Growth attributes	**0–15 cm**	**16–30 cm**	**31–45+ cm**
100-needle weight (g)	0.48 ± 0.12	0.52 ± 0.15	0.63 ± 0.15
Height (cm)	319 ± 71	313 ± 83	365 ± 89
dbh (mm)	44.6 ± 17.0	42.1 ± 17.8	55.5 ± 14.0
Volume (cm^3/tree)	3252 ± 2264	3107 ± 2984	5119 ± 3110

The chemical composition of the upper mineral and calcareous horizons among the three depth to carbonate classes was similar (Table 4). However, in the two shallower depth to carbonate classes, the slightly acidic upper mineral horizons account for a smaller proportion of the effective rooting zone. Thus, there would be differences in the soil chemistry within the rooting zone, particularly when the carbonate horizon was within 15 cm of the surface. This may be important during summer drought conditions. The surface acidic soil (surface organic and upper mineral horizon) may dry out, preventing roots from exploiting available nutrients such as Mn (Stone 1968). Manganese availability is low in the deeper calcareous layers (Table 4) where the available soil moisture is under summer drought conditions. Thus, the shallower the depth to carbonates, the more likely it is that deficiencies in nutrients such as Mn may occur.

TABLE 4 *Soil chemical properties of the surface organic horizon, non-calcareous mineral soil, and calcareous mineral horizon by carbonate depth class at East White River. Values are mean ± standard deviations.*

Depth to CO_3 class (cm)	Soil horizon (mean depth of layer)	pH ($CaCl_2$)	Organic carbon (%)	Total N ($g \cdot kg^{-1}$)	Exchangeable Ca ($cmol \cdot kg^{-1}$)	Exchangeable K ($cmol \cdot kg^{-1}$)	S ($mg \cdot kg^{-1}$)	Mn ($mg \cdot kg^{-1}$)
Forest floor								
0–15	2.7 ± 2.8	4.4 ± 0.7	44.7 ± 8.5	10.8 ± 2.8	37.7 ± 14.2	1.47 ± 0.51	76.1 ± 10.1	350 ± 193
16–30	3.1 ± 2.0	4.5 ± 0.5	41.9 ± 8.8	10.5 ± 1.9	43.0 ± 12.8	1.33 ± 0.47	82.2 ± 31.3	332 ± 135
31–45+	3.6 ± 1.9	4.6 ± 0.7	39.6 ± 11.1	9.2 ± 2.3	42.0 ± 17.3	1.25 ± 0.49	83.5 ± 19.1	325 ± 148
Weathered solum								
0–15	12.6 ± 3.8	5.6 ± 0.8	3.81 ± 1.95	1.35 ± 0.39	14.3 ± 9.6	0.20 ± 0.11	24.6 ± 9.2	22.5 ± 14.0
16–30	21.0 ± 3.9	5.4 ± 0.5	2.58 ± 0.91	1.16 ± 0.36	9.3 ± 5.8	0.16 ± 0.06	30.5 ± 15.8	15.6 ± 5.1
31–45+	32.5 ± 6.5	5.6 ± 0.7	1.96 ± 0.87	0.95 ± 0.38	7.7 ± 6.6	0.17 ± 0.04	22.1 ± 8.0	13.6 ± 2.8
Calcareous subsoil[a]								
0–15	22.2 ± 4.2	7.1 ± 0.2	0.75[b]	1.10 ± 0.42	31.0 ± 3.3	0.09 ± 0.04b[c]	45.3 ± 27.9	b.d.[d]
16–30	31.9 ± 3.8	7.0 ± 0.2	1.11	0.91 ± 0.33	29.1 ± 2.7	0.09 ± 0.03b	34.2 ± 6.8	b.d.
31–45+	43.6 ± 6.6	6.9 ± 0.2	0.76	0.96 ± 0.55	28.4 ± 2.7	0.14 ± 0.05a	34.6 ± 10.0	b.d.

[a] The mean depth of the calcareous horizon refers to the lowest depth sampled (i.e., the top 10 cm of this layer was typically sampled).

[b] In the calcareous horizon, organic C made up < 10% of the total C. No error estimates were calculated for these values.

[c] Within-soil layer means followed by different letters are significantly different at $\alpha = 0.05$ (all others non-significant).

[d] b.d. – below detection limit (2 $mg \cdot kg^{-1}$).

Foliar nutrition

There were no differences ($p > 0.05$) in the nutrient concentrations of current interior spruce foliage among depth to carbonate classes (Figure 1). Based on interpretations presented by Ballard and Carter (1986), nutrients that may be deficient in all the trees, regardless of depth to carbonates, were N and S.

The Ca concentrations tended to be higher (not significant at $p = 0.05$) in the needles of trees where the carbonates were within 15 cm of the surface. In contrast, the Mn concentrations in current needles of trees where carbonates were within 15 cm of the surface were 25% lower than the Mn concentrations in the trees where carbonates were > 30 cm depth (not significant at $p = 0.05$).

Deficiencies of Mn are often seen in limestone soils such as in the Alps or along the Mediterranean coast (Kavvadias and Miller 1999). A problem with diagnosis is that there are few definitive data on critical or toxic Mn levels. According to the interpretations of Ballard and Carter (1986), Mn deficiencies in conifers occur only at very low concentrations (< 15 $mg \cdot kg^{-1}$). In a detailed controlled experiment, Kavvadias and Miller (1999) found sub-optimal growth of Scots pine at foliar concentrations < 80 $mg \cdot kg^{-1}$ and maximum growth at 240–280 $mg \cdot kg^{-1}$. Visual symptoms were only occasionally observed, probably because foliar Mn concentrations were > 70 $mg \cdot kg^{-1}$ (Kavvadias and Miller 1999). In our study, the foliar Mn data were within the normal ranges; however, where foliar Mn levels are not below thresholds it is possible that there is an increased physiological cost associated with obtaining adequate nutrition. The needle concentrations of Fe, Zn, and P, often considered to be affected by high pH and calcareous soils, were similar among the depth to carbonate classes.

Another possible reason that no apparent deficiencies in some elements were observed may be related to the time of the foliage sampling. The tree foliage was collected in late September once the trees were dormant. For the more immobile elements in plant tissue such as Ca, Fe, Zn, and Mn, dormant-season foliage samples may be of limited value in identifying deficiencies that occurred during the growing season (Ballard and Carter 1986). For example, Mn and Fe deficiencies may occur during summer drought conditions and damage developing tissues, thus reducing growth, but it would not be reflected in the foliage nutrient concentration collected in the fall.

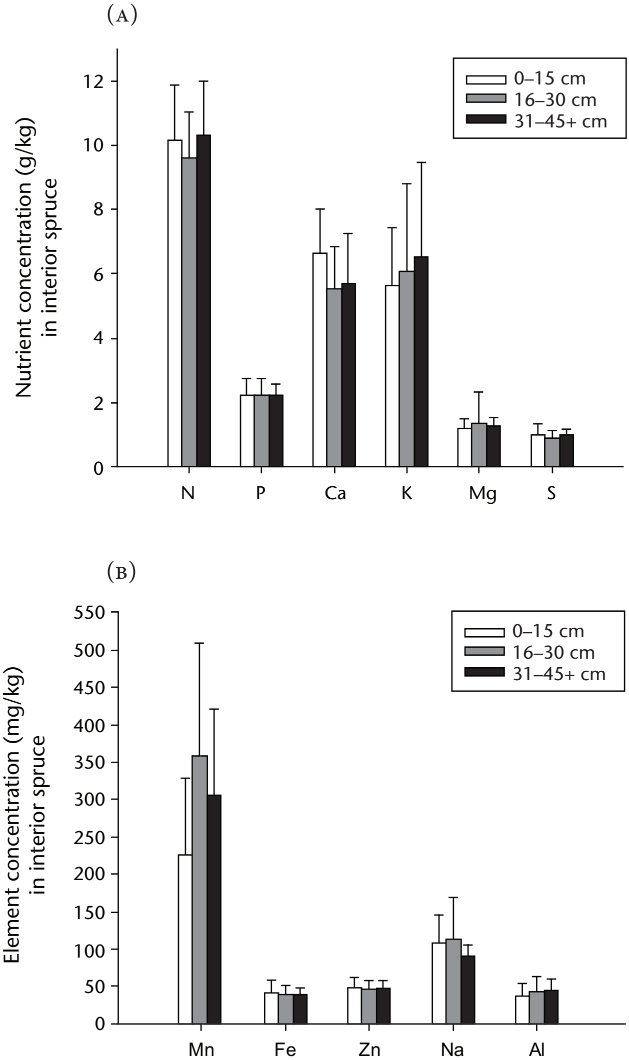

FIGURE 1 *Total nutrient concentrations (A: macronutrients and B: micronutrients) of interior white spruce by depth to carbonate class at East White River. Bars represent standard deviations.*

Growth responses

Individual soil chemical properties accounted for < 5% of the variability of any of the four growth attributes. Depth to carbonates accounted for a small (5–8.8%) but significant amount of the variation in growth (Table 5). Total N, Fe, and Mg needle concentrations were the only other variables that accounted for a significant amount of the variation associated with any of the growth parameters (Table 5). All variables were positively correlated to the growth parameters except Fe with 100-needle weight. Total Fe and N in the foliage and depth to carbonates accounted for 37% of the variation in the 100-needle weight. The variation in the other growth parameters ranged from a low of 12.5% for height to 25.8% for dbh (Table 5). There was only a weak influence of depth to carbonates on the growth of interior white spruce. These results are similar to those of Duffy (1964), who found that, in 60-year-old lodgepole pine in the eastern foothills, depth to carbonate was only weakly correlated to growth. Over a range of age classes, depth to carbonate accounted for a similar amount of the variation in growth, although it was not statistically significant.

Lussier River

Soil properties and growth response

The average depth to carbonates at Lussier River was about 10 cm deeper than at East White River, and carbonates were not found at any sampling location within the surface 15 cm (Table 3). Thus, only two depths to carbonate classes were assigned for the Lussier River site: 0–30 cm (n = 28) and 31–45+ cm (n = 32). The mean depth to carbonates was 24.4 cm for the 0–30 cm depth class and 39.6 cm for the 31–45+ cm depth class. The calcareous horizons contained 50.1 ± 10.6% and 39.1 ± 13.7% $CaCO_3$ equivalent for the 0–30 cm and 31–45+ cm depth class, respectively.

TABLE 5 *Explanatory variables, model R^2, and significance for forward stepwise multiple regression for height, dbh, volume, and 100-needle weight in interior spruce at East White River*

Growth attributes	Explanatory variable	Model R^2	*P-value*[a]
Height			
	Depth to CO_3	0.070	0.041
	Foliar Fe	0.055	0.063
	Total	0.13	–
dbh			
	Depth to CO_3	0.088	0.021
	Foliar Mg	0.085	0.019
	Foliar N	0.085	0.014
	Total	0.26	–
Volume			
	Foliar Mg	0.125	0.006
	Foliar N	0.064	0.038
	Depth to CO_3	0.052	0.055
	Total	0.24	–
100-needle weight			
	Foliar Fe	0.149	0.002
	Foliar N	0.143	0.001
	Depth to CO_3	0.087	0.007
	Total	0.37	–

[a] *P*-value is based on the sequential (Type I) sum of squares using an *F*-test.

There were no significant differences in growth among the 15 progeny sampled and there was no trend in growth related to depth to carbonates at the Lussier River site (Table 6). The soil chemistry for the Lussier site was much more variable than at the East White River site and there were few differences among carbonate depth classes for any of the soil horizons (Table 7). Stepwise forward multiple linear regressions provided no further insight into the role of carbonates at the Lussier site.

TABLE 6 *The 100-needle weight, height, dbh, and volume of interior spruce by depth class to carbonates at Lussier River. Values are means ± standard deviations.*

Growth attributes	**Depth to carbonates**	
	0–30 cm	**31–45+ cm**
100-needle weight (g)	0.55 ± 0.15	0.52 ± 0.14
Height (cm)	323 ± 111	315 ± 119
dbh (mm)	40.6 ± 15.1	40.8 ± 7.6
Volume (cm^3/tree)	2960 ± 2494	3290 ± 3652

TABLE 7 *Soil chemical properties of the surface organic horizon, non-calcareous mineral soil, and calcareous mineral horizon by carbonate depth class at Lussier River. Values are mean ± standard deviations.*

Depth to CO_3 class (cm)	Soil horizon	pH[a] ($CaCl_2$)	Organic carbon (%)	Total N ($g \cdot kg^{-1}$)	Exchangeable Ca ($cmol \cdot kg^{-1}$)	Exchangeable K ($cmol \cdot kg^{-1}$)	S ($mg \cdot kg^{-1}$)	Mn ($mg \cdot kg^{-1}$)
Forest floor								
0–30	5.5 ± 3.1	5.1 ± 0.9	39.2 ± 9.6	10.1 ± 2.7	32.9 ± 31.7	0.71 ± 0.49a[b]	64.0 ± 69.6	144 ± 270
31–45+	6.9 ± 3.6	5.8 ± 1.0	38.5 ± 8.6	10.0 ± 2.3	57.2 ± 63.4	0.58 ± 0.45b	83.4 ± 84.0	75.7 ± 75.9
Weathered solum								
0–30	24.4 ± 3.8	6.0 ± 0.7	2.96 ± 1.16	1.40 ± 0.50	16.4 ± 7.0	0.21 ± 0.06	21.6 ± 12.4	9.3 ± 4.3
31–45+	35.9 ± 7.5	6.4 ± 0.8	2.54 ± 1.22	1.30 ± 0.80	24.4 ± 29.7	0.27 ± 0.16	34.6 ± 37.8	12.2 ± 11.6
Calcareous subsoil[c]								
0–30	33.9 ± 5.0	7.0 ± 0.1	0.07[d]	1.0 ± 0.4	71.3 ± 60.6a	0.31 ± 0.30	63.5 ± 70.1	9.9 ± 8.2
31–45+	44.9 ± 5.1	7.0 ± 0.3	0.32	1.0 ± 0.3	55.8 ± 51.5b	0.33 ± 0.29	58.6 ± 58.7	10.4 ± 9.0

[a] pH in water is typically 0.4–0.5 pH units higher.

[b] Within-soil layer means followed by different letters are significantly different at $\alpha = 0.05$.

[c] The mean depth of the calcareous horizon refers to the lowest depth sampled.

[d] In the calcareous horizon, organic C made up < 10% of the total C. No error estimates were calculated for these values.

Comparison of foliar nutrients between EKC and EKA sites

The foliage concentrations of interior spruce at the Lussier River and East White River sites were compared to those from Horsethief Creek (Table 8). The soils of Horsethief Creek were derived from acidic parent material and no carbonates were present. Horesethief Creek was sampled at the same time of year but 1 year later than the two calcareous soils. Therefore, some of the differences in nutrient concentrations among sites may be attributed to climatic differences between years. The differences among the three sites were not consistent for the nutrients measured, indicating that site differences may also have been a factor.

The 100-needle weight and N concentration of current foliage were higher at Horsethief Creek compared to the two calcareous soils. In contrast, Ca, Mg, and S concentrations of current foliage were higher on the calcareous soils compared to Horsethief Creek. An increase in foliar concentrations of Ca and/or Mg are often associated with trees growing on calcareous soils, depending on the carbonate source. For example, Smith and Wass (1994b) observed higher Ca in current foliage of Douglas-fir and lodgepole pine on calcareous skidroads in

TABLE 8 *The 100-needle weight and total nutrient concentrations of current interior spruce foliage at two calcareous sites (East White River and Lussier River) and one acidic site (Horsethief Creek). Values are means ± standard deviations.*

	East White River	**Lussier River**	**Horsethief Creek**
100-needle weight (g)	0.54 ± 0.15b[a]	0.53 ± 0.14b	0.62 ± 0.16a
Nitrogen ($g \cdot kg^{-1}$)	9.90 ± 1.50b	9.80 ± 1.40b	11.1 ± 1.60a
Phosphorus ($g \cdot kg^{-1}$)	2.22 ± 0.47a	1.51 ± 0.64c	1.90 ± 0.25b
Potassium ($g \cdot kg^{-1}$)	6.11 ± 2.57b	7.03 ± 1.67a	7.09 ± 1.12a
Calcium ($g \cdot kg^{-1}$)	5.81 ± 1.41a	5.60 ± 2.33a	4.07 ± 1.03b
Magnesium ($g \cdot kg^{-1}$)	1.31 ± 0.76a	1.26 ± 0.37a	0.76 ± 0.17b
Sulfur ($g \cdot kg^{-1}$)	0.94 ± 0.24a	0.87 ± 0.14a	0.76 ± 0.10b
Manganese ($mg \cdot kg^{-1}$)	320 ± 142ab	281 ± 229b	338 ± 101a
Iron ($mg \cdot kg^{-1}$)	41.2 ± 9.9b	54.6 ± 12.4a	25.8 ± 15.0c
Zinc ($mg \cdot kg^{-1}$)	47.8 ± 10.9a	42.2 ± 18.2ab	38.6 ± 31.3b

[a] Mean values within rows followed by different letters are significantly different at the $\alpha = 0.05$ level.

the Rocky Mountain Trench. Higher S concentrations could also be associated with the calcareous material, depending on the soil parent material.

Deficiencies of P, K, Mn, Fe, and Zn are often associated with calcareous soils (Kishchuk 2000) but that is not evident from the foliar data in this study. Lower P, K, and Mn foliage concentrations were measured at only one of the calcareous sites compared to the acidic site. The Fe and Zn concentrations, particularly Fe, were lowest in the foliage from Horsethief Creek. This result is the opposite of what would be expected, as Fe and Zn concentrations are often cited as nutrients that are limited in calcareous soils. The reasons for the lower Fe concentrations in the foliage at Horsethief Creek are not known.

SUMMARY

The 20-year growth results of the study by Xie et al. (1998) indicated that interior spruce progeny (regardless of seed origin) grew faster (32%, on average) and survived better (8%, on average) on acidic soils than on calcareous soils. They indicated that the soil chemical conditions (i.e., calcareous soils) appeared to have considerable influence on the growth and survival of interior spruce. In contrast, they also found that trees originating from seed from the EKC zone were superior to those from the East Kootenay acidic soil zone, regardless of the zone in which they were planted. No explanation for the better performance of trees from calcareous origin was given. Xie et al. (1998) concluded that better growth and survival are expected by planting interior spruce from the EKC zone at acidic sites.

We confirmed that the soils designated calcareous and those designated acidic by Xie et al. (1998) were correct with one possible exception. However, we could not explain a mechanism to account for the poorer tree growth, nor elucidate a regional trend regarding the specific influence of calcareous material on nutrient availability and/or how it may influence tree growth. At the East White River site there was a trend for poorer growth when the trees were growing in soils where the carbonates were present within 30 cm of the surface. The strength of carbonate (i.e., % $CaCO_3$ equivalent) was also greater at the shallower depth. However, growth differences were not statistically significant, probably because of the high within-site soil variability.

There was no clear indication if nutrient deficiencies or imbalances were the cause. At the Lussier River site, carbonates were on average deeper than at East White River and there was no trend in tree growth related to carbonate depth.

Comparisons of the foliage chemistry between the two calcareous sites and an acidic site showed some nutrient differences that are probably associated with the carbonates (i.e., higher Ca and Mg concentrations in the foliage from the calcareous sites). None of the differences, however, appeared to be related to a carbonate-induced nutrient deficiency. Additional sampling possibly at different times of the year may help elucidate the nutritional aspect of carbonates on tree growth.

The results at East White River suggest that carbonates may affect interior spruce growth; however, overall the results are inconclusive. More work is needed to determine how carbonates are a contributing factor in growth reductions and under what conditions, such as what depth and strength, or soil disturbance regime, will carbonates affect growth. Studies currently under way on BCFS fertilizer trials and the Long-Term Soil Productivity (LTSP) sites in the East Kootenays will hopefully provide further insight into the role of carbonates on tree growth and the sensitivity of calcareous soils to disturbance.

This study adds to the knowledge base, indicating that calcareous soils, particularly those in which carbonates are within 30 cm of the surface, may be more sensitive to disturbance. The soil disturbance hazard ratings and soil disturbance limits for sensitive soils from the previous Forest Practices Code recognized this (based on previous research and experience) and these hazard ratings and disturbance limits have been carried forward under the *Forest and Range Practices Act*. Thus, management practices that minimize the potential detrimental effects of forest operations on calcareous soils should be implemented, particularly in regard to displacing the acidic topsoil layer and exposing the calcareous subsoil.

APPENDIX 1 Soil profile information for the study sites visited

Acidic sites	Horizon	Depth (cm)	Presence or absence of CO_3	pH
Perry Creek	LF	5–0	nil	N.A.
	Bm	0–7	nil	4.82
	BCI	7–25	nil	4.42
	BCII	25–47	nil	4.23
	C	47+	nil	4.30
Jumbo Creek (side slope)	LFH	1–0	nil	N.A.
	Bm	0–29	nil	5.76
	BC	29–41	nil	6.07
	C	41–50+	nil	6.24
Jumbo Creek (fluvial)	LFH	1–0	nil	N.A.
	C	0–5	nil	4.33
	Ae	Trace	nil	No sample
	CI	5–27	nil	4.38
	CII	27–49	nil	5.50
	CIII	49–54+	nil	5.36
Horsethief Creek (side slope)	LFH	1.5–0	nil	N.A.
	Bm	0–8	nil	4.29
	BC	8–16	nil	4.88
	CI	16–33	nil	5.15
	CII	33–52+	nil	6.42
Horsethief Creek (fluvial)	LFH	2–0	nil	N.A.
	CI	0–18	nil	5.50
	CII	18–33	nil	5.81
	CIII	33–55	nil	6.67
	CIV	55–62+	nil	6.30
Bloom Creek	FH	3–0	nil	N.A.
	Ah	0–3	nil	5.62
	Bfh	3–17	nil	5.39
	BC	17–39	nil	5.41
	C	39–44+	nil	5.62

APPENDIX 1 (Continued)

Calcareous sites	Horizon	Depth (cm)	Presence or absence of CO_3	pH
Windermere Creek	LFH	4–0	nil	N.A.
	Bm	0–33	nil	6.86
	BCk	33–42	strong	7.44
	CIk	42–52	strong	7.42
	CIIk	52+	strong	7.59
Windermere Creek	LFH	3–0	nil	N.A.
	Bm	0–22	nil	6.23
	BCk	22–49	strong	7.42
	BCIIk	49–54+	strong	7.57
Lodgepole Creek	LFH	1–0	nil	N.A
	Ae	Trace	nil	No sample
	Bm	0–21	nil	5.17
	BCI	21–36	nil	5.55
	BCII	36–53	nil	6.96
	Ck	53–60+	strong	7.42
Lodgepole Creek (fluvial)	LFH	1–0	nil	N.A.
	Bmj	0–19	nil	4.03
	CI	19–32	nil	4.58
	CII	32–64	nil	6.62
	Ck	64–71+	moderate	7.25

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