NOTE / NOTE

Unusual effect of controlling aboveground competition by *Ledum groenlandicum* on black spruce (*Picea mariana*) in boreal forested peatland

Martin Lavoie, David Paré, and Yves Bergeron

Abstract: Poor growth of black spruce (*Picea mariana* (Mill.) BSP) has been associated with the presence of *Ledum groenlandicum* L. (*Ledum*) on some sites in the eastern boreal forest in Canada. To increase black spruce productivity on lowland sites, a study was carried out to test the effect of mechanical control of *Ledum* (by clipping) on black spruce growth on forested peatland in northwestern Quebec. We compared the growth and foliar nutrient concentrations of advance-regeneration black spruce seedlings with and without *Ledum* control. Contrary to our expectations, our results showed that 3-year control of aboveground competition by *Ledum* decreased rather than increased black spruce growth and had no effect on foliar nutrient concentrations. *Ledum* grows on a variety of site types; therefore, the mere presence of this species does not necessarily indicate that there will be a problem with conifer regeneration (growth and germination).

Résumé : Une diminution dans la croissance de l'épinette noire (*Picea mariana* (Mill.) BSP) a été associée à la présence du *Ledum groenlandicum* L. (*Ledum*) sur certains sites dans la forêt boréale de l'est du Canada. Avec comme objectif d'augmenter la productivité de l'épinette noire dans les stations des basses-terres, une étude a été entreprise afin de mesurer l'effet du contrôle mécanique du *Ledum* sur la croissance de l'épinette noire dans une tourbière boisée située dans le nord-ouest du Québec. Nous avons comparé la croissance et les concentrations foliaires de nutriments de semis d'épinette noire dans des parcelles avec et sans contrôle du *Ledum*. Contrairement à nos attentes, nos résultats ont montré qu'un contrôle de la compétition épigée du *Ledum* pendant trois ans résultait en une baisse plutôt qu'une augmentation de la croissance de l'épinette noire et n'occasionnait pas de différence dans les concentrations foliaires de nutriments. Le *Ledum* croit sur différents types de sites et la présence de cette espèce n'indique pas nécessairement un problème avec la régénération de conifères (croissance et germination).

Introduction

In the eastern boreal forest of Canada, competition with ericaceous species occurs mainly with sheep laurel, *Kalmia angustifolia* L. (Inderjit and Mallik 1996*b*, 2002; Wallstedt et al. 2002; Yamasaki et al. 2002), and bog Labrador tea, *Ledum groenlandicum* Oeder (hereinafter referred to as *Ledum*) (Inderjit and Mallik 1996*a*, 1997). In most studies, the effect of *K. angustifolia* on black spruce (*Picea mariana* (Mill.) BSP) rather than the effect of *Ledum* has been examined.

Ledum is a very common perennial understory shrub in the boreal forest, especially in moder and mor humus, in forested peatlands, and in wet soils with thick humus (Jobidon 1995; Inderjit and Mallik 1996*a*). As early as 1948, LeBarron (1948) associated the presence of *Ledum* with reduced black spruce growth. In northwestern Quebec, a negative correlation between *Ledum* and black spruce growth on lowland sites has also been measured (Fenton et al. 2005; Lavoie et al. 2006). It has been suggested that *Ledum* may interfere with black spruce growth by means of (*i*) allelopathic compounds (phenolics) that could stimulate

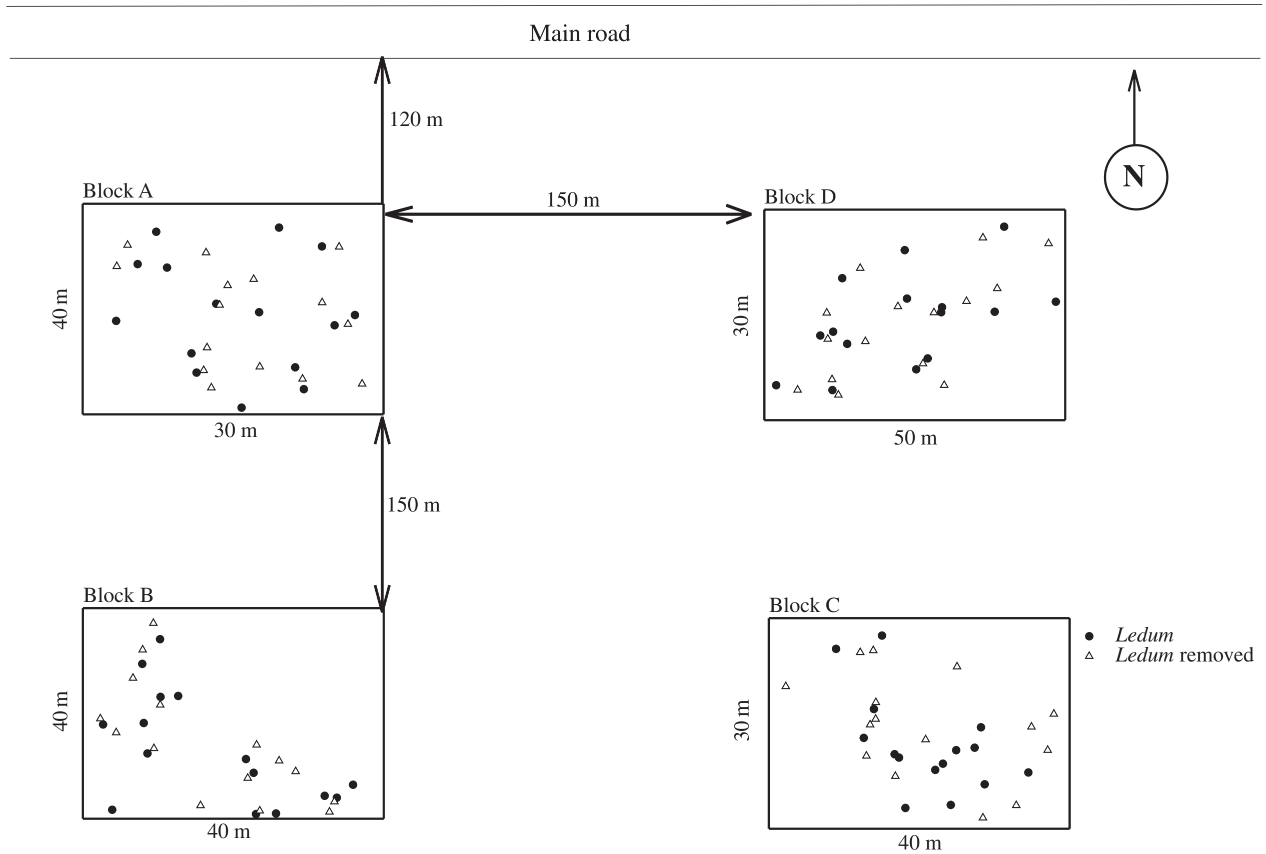
Received 28 February 2006. Accepted 14 April 2006. Published on the NRC Research Press Web site at http://cjfr.nrc.ca on 2 August 2006.

M. Lavoie[1] and Y. Bergeron. Groupe de recherche en écologie forestière interuniversitaire (GREFi) and Chaire industrielle CRSNG-UQAT-UQAM en aménagement forestier durable, Université du Québec en Abitibi–Témiscamingue, 445 boulevard de l'Université, Rouyn-Noranda, QC J9X 5E4, Canada.
D. Paré. Laurentian Forestry Centre, Canadian Forest Service, Natural Resources Canada, 1055 du P.E.P.S., P.O. Box 10380, Stn. Sainte-Foy, Quebec, QC G1V 4C7, Canada.

[1]Corresponding author (e-mail: martin_skifond@hotmail.com).

 doi:10.1139/X06-102

Fig. 1. Experimental design showing the four blocks, each containing 15 black spruce trees with (●) and without (△) control of aboveground competition by *Ledum groenlandicum*.



microbial activity that reduces soil nitrogen (N), (*ii*) allelopathic compounds that affect spruce–mycorrhizal symbiosis, (*iii*) phenolics that may have direct effects on plant growth, (*iv*) competition for nutrients, or (*v*) alteration of soil chemistry (Inderjit and Mallik 1996*a*, 1997).

To increase black spruce productivity on these lowland sites, we wanted to test whether the removal of *Ledum* would benefit black spruce growth. In Quebec, the use of chemical herbicides on public land is forbidden, and vegetation control in forested stands is done exclusively using mechanical (scarification, brush-cutting, clipping) techniques. Thus, the main objective of this study was to determine the effect of manual cutting of competing aboveground *Ledum* with a brush saw over a 3-year period on the growth and foliar nutrient concentrations in naturally regenerated black spruce.

Material and methods

Study area

The study was conducted in a young black spruce stand in northwestern Quebec, 100 km north of La Sarre (49°51′N, 78°38′W) that was initiated following clear-cutting in the winter of 1987. The previous stand was cut 15 years earlier, but regeneration tree age (at the root collar) varied between 7 and 35 years (n = 16) because of the high abundance of layers that were established prior to clear-cutting. The study site is dominated by black spruce accompanied by balsam fir (*Abies balsamea* (L.) Mill.), tamarack (*Larix laricina* (Du Roi) K. Koch), and trembling aspen (*Populus tremuloides* Michx.). The shrub cover is dominated by *Ledum*, with less than 10% of the remaining cover consisting of sheep laurel, leatherleaf (*Chamaedaphne calyculata* (L.) Moench), and blueberry (*Vaccinium* spp.). *Sphagnum* mosses and feather mosses (mainly Schreber's big red stem moss, *Pleurozium schreberi* (Brid.) Mitt.) cover the forest floor and form hummocks and hollows on the site. The study area is typical of the clay belt located in northern Quebec and Ontario, a territory that is characterized by glacial lacustrine deposits left by the glacial lakes Barlow and Ojibway (Vincent and Hardy 1977). The study area is part of the Lake Matagami Lowland ecological region within the western black spruce – feather moss bioclimatic domain (Saucier et al. 1998). At a nearby weather station (Joutel, Quebec), mean annual temperature is 0.1 °C, annual precipitation is 892 mm, and there are 64 frost-free days a year (Environment Canada 2004).

Sampling design

A large site (10 ha) with flat topography (<2% slope), a thick organic layer, and dense and homogeneous *Ledum* cover was selected. The great majority of trees on this site were short (less than 1.3 m in height). The site contained a few taller trees (2–4 m) that were excluded from the study because they were presumably remnants and, prior to treatment application, had not been subjected to any aboveground competition by the shrubby layer. Four blocks (1200,

Table 1. Pretreatment stand and site conditions in a 15-year-old stand of black spruce with and without control of aboveground competition by *Ledum groenlandicum*.

	Tree without *Ledum*[a]	Tree with *Ledum*[a]	*F*	*p* > *F*
Black spruce shoot height (cm)	65.7 (1.9)	65.2 (2.5)	0.02	0.876
Black spruce root-collar diameter (mm)	12.0 (0.6)	11.7 (0.6)	0.15	0.698
Three-year annual increments (cm)	18.7 (0.9)	19.0 (0.9)	0.14	0.708
Ledum shoot height (cm)	35.5 (1.2)	35.0 (1.1)	0.04	0.839
Ledum cover (%)	72.9 (2.6)	65.8 (2.6)	3.24	0.074
Thickness of organic layer (cm)	62.8 (3.9)	65.5 (3.7)	0.25	0.619

[a]Values are given as the mean with the standard error in parentheses.

1300, 1500, and 1600 m^2), spaced 150 m apart, were set up (Fig. 1). The area covered by each block varied and blocks were chosen to ensure that each contained 30 regenerating trees. Half of the selected trees in each block were randomly assigned to the brush-cutting treatment or left as an undisturbed control (n = 120 in total). Regenerating trees were classified by height (maximum 1.3 m) rather than by age. The age of trees was not determined and they could be older or younger than the clearcut (1987). Their origin (layer or seed) was not determined, but we suspect that they were mostly of layer origin, since a similar site (10 km away) revealed that 87% of the trees were of layer origin 7 years following clear-cutting (M. Lavoie, D. Paré, and Y. Bergeron, unpublished data). The area of *Ledum* to be treated around each tree had a radius equivalent to the total height of the tree. Aboveground removal of *Ledum* and accompanying vegetation was carried out in the first week of June 2003 (before the growing season, 16 years after clear-cutting), with new growth removed again in late August of 2003 and 2004 and in early June 2005. *Ledum* was clipped manually with a brush cutter (Efco, model 8753BAV) at ground level. No heavy equipment was used, to prevent damage to the surrounding vegetation and soil. At the beginning of the experiment (in June 2003, before the growing season), total height, the last three annual height increments (2000, 2001, 2002), and root-collar diameter were measured. The percentage of *Ledum* cover was estimated (visually) through a radius quadrat (boundary-less), while total height of *Ledum* was measured with a measuring tape (four measurements around each tree). The thickness of the organic layer was measured with a soil auger (two measurements) approximately 40 cm from the tree. In September 2005, total height, 3-year annual increments (i.e., 2003, 2004, 2005), and root-collar diameter were measured again. Needle samples (current year; a composite of lateral shoots (four or five) and leader) were collected from 10 random seedlings (5 treated, 5 control) from each block (n = 40 in total).

Foliar analyses

Needle samples were oven-dried at 70 °C for 48 h. After drying, needles were separated from the twigs and ground. Total carbon (C) and N were determined on a CNS analyzer, while total cations and phosphorus (P) were determined following calcination at 500 °C and dilution with hydrochloride (Miller 1998). Cations were analyzed by atomic absorption and P by colorimetry (Lachat Instruments, Milwaukee, Wis.).

Aerobic zones

One month after treatment, steel rods were driven into the soil beside (<20 cm away) five randomly chosen seedlings in each block with (n = 3) and without (n = 2) aboveground *Ledum* (i.e., 10 rods per treatment, for a total of 20) and left for a period of 6 weeks (3 July to 22 August 2003). The distance from the soil surface to the bottom of the orange/brown rust zone was measured to assess the depth of the oxygen zone (Carnell and Anderson 1986; Bridgham et al. 1991; Fenton et al. 2006).

Statistical analyses

A mixed linear model was used to compare the effect of *Ledum* control on 3-year cumulative root collar diameter growth, on height growth per year as repeated measurements, on foliar nutrient concentrations, and on depth of the aerobic zone. The significance of the block × treatment term (error A) was evaluated using Akaike's Information Criterion. This term was not significant and was removed from the model so that the parameters could be evaluated on an error term with 42 degrees of freedom (i.e., 15-1 (trees within blocks and treatment) × 3 (block × treatment)) for root collar diameter growth, with 112 degrees of freedom (i.e., 15-1 (trees within blocks and treatment) × 8 (block × treatment × year)) for height growth per year as repeated measures, 6 degrees of freedom (i.e., 3-1 (trees within blocks and treatment) × 3 (block × treatment)) for depth of the aerobic zone, and 12 degrees of freedom (i.e., 5-1 (trees within blocks and treatment) × 3 (block × treatment)) for foliar nutrient concentrations. Data were checked for independence, normality, and equality of variance prior to statistical analyses. Annual height growth and root-collar diameter were log-transformed when necessary to achieve normality. All statistical analyses were carried out using SAS version 8.02 (SAS Institute Inc. 2001).

Results

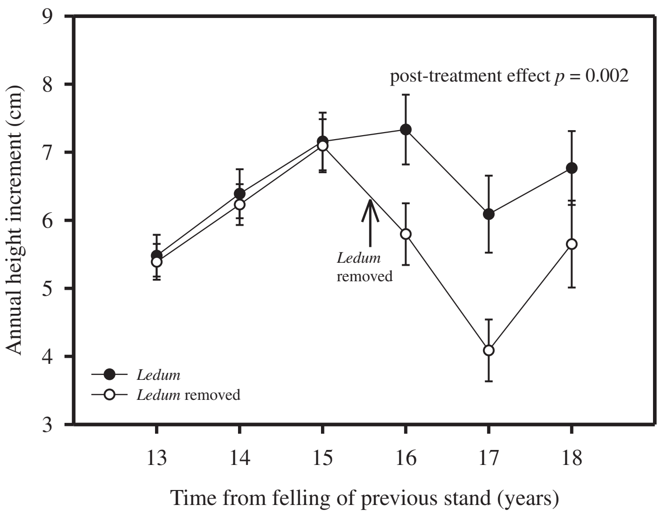
There were no significant differences in tree or site conditions before treatment (Table 1). Overall total mean height and root-collar diameter of black spruce before treatment were 65 cm and 12 mm, respectively (Table 1). Mean cover and height of *Ledum* were about 70% and 35 cm, respectively (Table 1). The thickness of the organic layer was 62.8 and 65.5 cm for treated and control trees, respectively (Table 1).

Table 2. Foliar nutrient concentrations in regenerating black spruce with and without control of aboveground *Ledum*.

	Tree without *Ledum*[a]	Tree with *Ledum*[a]	F^b	$p > F^b$
Carbon concn. (%)	49.94 (0.14)	49.75 (0.17)	0.66	0.421
Nitrogen concn. (%)	1.05 (0.04)	1.06 (0.05)	0.34	0.565
Phosphorus concn. ($g \cdot kg^{-1}$)	0.91 (0.02)	0.89 (0.02)	0.15	0.700
Calcium concn. ($g \cdot kg^{-1}$)	5.10 (0.22)	5.08 (0.20)	0.01	0.916
Magnesium concn. ($g \cdot kg^{-1}$)	1.07 (0.03)	1.02 (0.05)	0.59	0.449
Potassium concn. ($g \cdot kg^{-1}$)	4.06 (0.18)	4.04 (0.17)	0.00	0.987

[a]Values are given as the mean with the standard error in parentheses.
[b]Results of a mixed linear model describing the effects of removal of *Ledum* on foliar nutrient concentrations.

Fig. 2. Annual height increment of regenerating black spruce with and without control of aboveground competition by *Ledum* (one-way ANOVA with repeated measures).



The removal of aboveground competition by *Ledum* significantly reduced annual height growth during the 3-year period. The absence of a significant year × treatment effect indicated that this effect was similar for all 3 years (Fig. 2). There were no significant differences in the 3-year root collar diameter increment ($F = 2.23$, $p > F = 0.139$) or in foliar nutrient concentrations three growing seasons after the removal of aboveground competition by *Ledum* (Table 2). However, nutrient values for both treatments showed deficiency of N and P and excess of consumption of calcium (Stewart and Swan 1970; Lowry 1975).

The control of aboveground competition by *Ledum* did not affect the aerobic zone, which had an average depth of 28 cm ($F = 0.00$, $p > F = 0.979$).

Discussion

In the eastern boreal forest of Canada, poor growth and low germination rate of black spruce have been associated with the presence of *Ledum* (Inderjit and Mallik 1996*a*, 1997; Fenton et al. 2005; Lavoie et al. 2006). Since low-severity wildfires and current harvesting techniques (i.e., careful logging) in the eastern boreal forest in Canada generally favour *Ledum* growth and expansion (Groot 1996; Dussart and Payette 2002; Mallik 2003), concerns have been expressed regarding the effect of this species on conifer regeneration. Contrary to our expectations, our results showed that controlling aboveground *Ledum* over 3 years decreased black spruce growth and had no effect on foliar nutrient concentrations. The absence of an effect of *Ledum* on the black spruce germination rate was also observed by Titus et al. (1995).

We initially predicted that the reduction in black spruce growth was caused by an increase in the water table due to a reduction in precipitation (rain and snow) interception and a reduction in evapotranspiration by *Ledum*. However, our results showed that the depth of the aerobic zone did not differ between treatments. Moreover, based on foliar-nutritional interpretation of directional changes from vector analysis, the absence of differences in foliar nutrient concentrations (sufficiency-shift B: increase in mass and content but not in concentration) for trees with and without aboveground *Ledum* suggests steady-state nutrition (Salifu and Timmer 2001). This indicates that as black spruce growth was reduced by the removal of *Ledum*, foliar nutrient uptake was also decreased without an appreciable change in concentrations, which means that the reduction in nutrient uptake matched the reduction in growth (Boivin et al. 2002).

Ledum grows on a wide range of site types, therefore we conclude that the mere presence of this species does not necessarily indicate that there will be a problem with regeneration. Very little work has been done on quantifying the effect of *Ledum* on black spruce growth and it is therefore possible that our study site was non-problematic, and control of *Ledum* would confer no advantage on conifer growth. Previous studies showing a negative effect of *Ledum* on black spruce growth were either carried out on different sites with different environmental conditions (i.e., substrates, organic-layer thickness, water-table level) (Inderjit and Mallik 1996*b*) or based on a negative correlation between growth and the presence of *Ledum* (Fenton et al. 2005; Lavoie et al. 2006). In the current study, regenerating trees with and without control of aboveground *Ledum* were growing on the same site with similar field conditions, which allowed us to measure the direct effect of aboveground *Ledum* on black spruce growth. Even though this study was based on only one site, one site type, and one treatment type, the results suggest that *Ledum* may not be as universally problematic as was previously assumed. Further research across a range of site types is required to better understand the effect (positive or negative) of *Ledum* on black spruce germination and growth.

Acknowledgements

We thank two anonymous reviewers for valuable comments on an earlier version of the manuscript. We are grateful to Benoit Lafleur and Gabriel Diab for technical assistance in the field, Isabelle Lamarre for editing, and Alain Courcelles for laboratory analysis. We also thank Tembec Industries Inc. for their collaboration during the research. The study was funded by the NSERC-UQAT-UQAM Industrial Chair in Sustainable Forest Management, GREFi, Tembec Industries Inc., the Canadian Forest Service, and the Lake Abitibi Model Forest. The senior author received a scholarship from the Natural Sciences and Engineering Research Council of Canada (NSERC) and from the Fonds québécois de la recherche sur la nature et les technologies.

References

Boivin, J.R., Miller, B.D., and Timmer, V.R. 2002. Late-season fertilization of *Picea mariana* seedlings under greenhouse culture: biomass and nutrient dynamics. Ann. For. Sci. **59**: 255–264.

Bridgham, S.D., Faulkner, S.P., and Richardson, C.J. 1991. Steel rod oxidation as a hydrologic indicator in wetland soils. Soil Sci. Soc. Am. J. **55**: 856–862.

Carnell, R., and Anderson, M.A. 1986. A technique for extensive field measurement of soil anaerobism by rusting of steel rods. Forestry, **59**: 129–140.

Dussart, E., and Payette, S. 2002. Ecological impact of clear-cutting on black spruce – moss forests in southern Québec. Ecoscience, **9**: 533–543.

Environment Canada. 2004. Canadian climatic normals 1971–2000. Canadian Climatic Program, Atmospheric Environment Service, Downsview, Ont.

Fenton, N., Lecomte, N., Légaré, S., and Bergeron, Y. 2005. Paludification in black spruce (*Picea mariana*) forests of eastern Canada: potential factors and management implications. For. Ecol. Manage. **213**: 151–159.

Fenton, N., Légaré, S., Bergeron, Y., and Paré, D. 2006. Soil oxygen within boreal forests across an age gradient. Can. J. Soil Sci. **86**: 1–9.

Groot, A. 1996. Regeneration and surface condition trends following forest harvesting on peatlands. Northern Ontario Development Agreement/Northern Forestry Program Tech. Rep. TR-26.

Inderjit, and Mallik, A.U. 1996*a*. Growth and physiological responses of black spruce (*Picea mariana*) to sites dominated by *Ledum groenlandicum*. J. Chem. Ecol. **22**: 575–585.

Inderjit, and Mallik, A.U. 1996*b*. The nature of interference potential of *Kalmia angustifolia*. Can. J. For. Res. **26**: 1899–1904.

Inderjit, and Mallik, A.U. 1997. Effects of *Ledum groenlandicum* amendments on soil characteristics and black spruce seedling growth. Plant Ecol. **133**: 29–36.

Inderjit, and Mallik, A.U. 2002. Can *Kalmia angustifolia* interference to black spruce (*Picea mariana*) be explained by allelopathy? For. Ecol. Manage. **160**: 75–84.

Jobidon, R. 1995. Autoécologie de quelques espèces de compétition d'importance pour la régénération forestière au Québec : revue de littérature. Direction de la recherche forestière, Ministère des Ressources naturelles du Québec, Québec, Que.

Lavoie, M., Paré, D., and Bergeron, Y. 2006. Relationship between micro-site type and the growth and nutrition of young black spruce on post-distributed lowland black spruce sites in eastern Canada. Can. J. For. Res. **36**. In press.

LeBarron, R.K. 1948. Silvicultural management of black spruce in Minnesota. USDA For. Serv. Circ. No. 791.

Lowry, G.L. 1975. Black spruce site quality as related to soil and other site conditions. Soil Sci. Soc. Am. Proc. **39**: 125–131.

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.

Miller, R.O. 1998. High-temperature oxidation: dry ashing. *In* Handbook of reference methods for plant analysis. *Edited by* Y.P. Kalra. Soil and Plant Analysis Council and CRC Press, Boca Raton, Fla. pp. 53–56.

Salifu, K.F., and Timmer, V.R. 2001. Nutrient retranslocation response of *Picea mariana* seedlings to nitrogen supply. Soil Sci. Soc. Am. J. **65**: 905–913.

SAS Institute Inc. 2001. SAS OnlineDoc, version 8.02 [computer program]. SAS Institute Inc., Cary, N.C.

Saucier, J.-P., Bergeron, J.-F., Grondin, P., and Robitaille, A. 1998. Les régions écologiques du Québec méridional (3e version). Aubelle, **124** (Suppl.): S1–S12.

Stewart, H., and Swan, H.S.D. 1970. Relationships between nutrient supply, growth and nutrient concentrations in the foliage of black spruce and jack pine. Woodland Pap. No. 19, Pulp and Paper Research Institute of Canada, Pointe-Claire, Que.

Titus, B.D., Sidhu, S.S., and Mallik, A.U. 1995. A summary of some studies on *Kalmia angustifolia* L.: a problem species in Newfoundland forestry. Inf. Rep. N-X-296, Canadian Forest Service Newfoundland and Labrador Region, Natural Resources Canada, St. John's.

Vincent, J.-S., and Hardy, L. 1977. L'évolution et l'extension des lacs glaciaires Barlow et Ojibway en territoire québécois. Geogr. Phys. Quat. **31**: 357–372.

Wallstedt, A., Coughlan, A., Munson, A.D., Nilsson, M.-C., and Margolis, H.A. 2002. Mechanisms of interaction between *Kalmia angustifolia* cover and *Picea mariana* seedlings. Can. J. For. Res. **32**: 2022–2031.

Yamasaki, S.H., Fyles, J.W., and Titus, B.D. 2002. Interactions among *Kalmia angustifolia*, soil characteristics, and the growth and nutrition of black spruce seedlings in two boreal Newfoundland plantations of contrasting fertility. Can. J. For. Res. **32**: 2215–2224.